BRITISH MINING

A TREATISE

ON THE

HISTORY, DISCOVERY, PRACTICAL DEVELOPMENT AND FUTURE PROSPECTS

OF

METALLIFEROUS MINES

IN THE

UNITED KINGDOM

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BRITISH MINING.

BOOK I.

HISTORICAL SKETCH OF BRITISH MINING.

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BRITISH MINING.

BOOK I.

HISTORICAL SKETCH.

CHAPTER I.

MINING PREVIOUS TO THE ROMAN INVASION OF BRITAIN.

TIN.—There are certainly evidences which appear to prove that the British Isles have yielded mineral treasures, for the use of man, for not less than three thousand years. Tradition whispers—very indistinctly it is true—that certain spots were visited, long before the Christian era, by traders from an Eastern country, who sought for, and discovered, a district producing tin. Indications of old mine workings—such as holes pierced in the faces of the cliffs, and shallow pits dug on the sides of the hills—are found existing to the present day, throughout the length and breadth of Cornwall, which are unmistakably of great antiquity. We learn from the present inhabitants that these are "old men's workings," the remains of the "Sarcens," or strangers —"Jews' pits" and the like—but of the age of those diggings we glean nothing. Vast heaps of detrital matter are not unfrequently met with, evidently the result of subterranean—but shallow—operations, and these are in many places called "Attal-Saracen,"* or, the waste of the stranger, and in others they are spoken of as "Jews' leavings." From these we are led to infer, not that Saracens ever worked the tin mines, but that oriental strangers did, in this country, establish those searches for a metal valuable to them.

It should not be forgotten that in the time of Moses at least six metals were known. He says of the spoils of the Midianites, "Only the gold and the silver, the brass, the iron, the tin, and the lead" shall be purified by fire.†

Although we have only conjecture to guide our inquiries into the age of the ancient mineral works in these islands, there are collateral evidences supporting the hypothesis, which points to the very early employment of

* *Attal-Sarsen* is probably the correct term, although commonly pronounced "*Saracen*," under some misconception that the name applies to the Saracens or Moors. *Sarsen* signifies simply *the stranger* and in this sense it is applied to the "*Sarsen Stones*" on Salisbury Plain, meaning stones brought from some other district.

† Numbers xxxi. 22.

Cornish tin in the manufacture of the brass of the sacred writings, and the bronzes of Assyria and of Egypt. It is desirable that a few of those evidences should be examined.

Ezekiel (chap. xxvii. ver. 12) the prophet, who wrote about six hundred years before Christ, speaking of the commercial wealth of Tyre, says: "Tarshish was thy merchant by reason of the multitude of all kinds of riches; with silver, iron, *tin*, and lead, they traded in thy fairs." The Greeks used tin before the Trojan war. This metal is mentioned by Homer as forming a corslet presented by the King of Cyprus to Agamemnon. Consequently tin must have been known at least sixteen centuries before Christ. From this it is evident that a large trade in the metals named must have been established from a remote period. Herodotus, who wrote B.C. 440, admits his want of knowledge as to the source from which amber is derived, and he continues, "Neither am I better acquainted with the islands called the *Cassiterides*, from which we are said to have our tin."

Wheeler, in his "Geography of Herodotus," correctly says: "He knew the Etruscans, whose commerce extended far and wide, and he had some dim, doubtful notions, about the Cassiterides, or Tin Islands. But of the inhabitants of our present France, or Britain, or Germany, the universal geographer had heard nothing."

Bronze weapons, tools, and ornaments were used by man in the very youth of his history. This metal is well known to be an alloy of copper with tin. There can be no question but that the tin was obtained from one of three sources. It was either derived from some of the islands of the Indian Archipelago, or from Spain, or from the British Isles. Mr. W. D. Cooley, in his "Maritime and Inland Discovery," vol. i. p. 131, writes evidently without sufficiently examining the question. "There can be no difficulty in determining the country from which tin first arrived in Egypt. That metal was in all ages a principal export of India: it is enumerated as such by Arrian, who found it abundant in the ports of Arabia, at a time when the supplies of Rome flowed chiefly through that channel. The tin mines of Banca are probably the richest in the world. But tin was unquestionably brought *from* the West at a *later* period." Dean Vincent, in his "Commerce and Navigation of the Ancients in the Indian Ocean," refers especially to the Periplus of Arrian—not the Arrian of Nicomedia, who wrote the Life of Alexander the Great—but a merchant of Alexandria in Egypt, who, having himself made many voyages to India and Ceylon, collected the information obtained, and published it under the title of "The Periplus of the Erythræan Sea." While the exports from Masuah-Abyssinia are stated to be ivory and rhinoceros' horns; amongst the imports we find *white copper* for ornaments and coins; brass for culinary vessels and personal ornaments; iron for spear-heads and of Indian temper. The imports into Abalites, close to the Straits of Babelmandeb, consisted amongst other things of tin in small quantity. Kane, a port on the coast of Arabia, imported from Egypt, amongst cottons, silks, and similar articles, brass and tin. The imports into Barugaza, a port in the Gulf of Cambay, included brass, tin, lead, ore of cinnabar, and stibium (the sulphide of antimony) for tinging the eyes. The port of Baráhi—believed to be the extreme point reached by Arrian in

his voyages—lying midway between Goa and Cape Comorin, *received from* Egypt, *stibium* (antimony), with brass, tin, lead, cinnabar, and orpiment. In all this we find that tin was sent to Eastern ports, but we discover no trace of tin as being imported into Egypt from India. Tin was evidently known and recognised as an article of traffic in the most ancient times; but instead of being brought from the East to the West by the merchants of Egypt, it is invariably exported from that country to the East.* All this is strongly opposed to the statement which has been quoted from Cooley's work. The existence of tin in India is undoubted. The island of Banca and many of the smaller neighbouring islands must have produced tin, and this metal was also found in Burmah, Siam, and Malacca, the southern promontory of Asia. It is not improbable, therefore, that some tin might have been brought into the Red Sea, or into Egypt, by an overland route from India.

Layard, for example, in his "Nineveh," vol. ii. p. 419, says: "I am not aware of the existence of tin within the limits of Assyria. Still the Assyrians and the adjoining nations must have obtained this metal from their own dominions, or from some country to the *east* of them, as it is mentioned among the objects of tribute brought to the Egyptians from that part of Asia. The probability is, that the tin used in the manufacture of the bronzes of the Assyrians was brought by caravans from the East, and that the copper was procured from the copper mines in Arabia." These quotations have been made for the purpose of showing that a considerable amount of ingenious argument has been expended in the endeavour to prove one side only of a question. The navies which were employed in bringing treasures to Solomon *might* have brought tin from the East, at the same time as the Tyrian merchants were obtaining the same metal from the West, but we do not discover that they traded to any extent in that metal. Tradition and history regard the people of Phœnicia as the merchant traders who discovered—while Rome was yet in its infancy—the Western land from which tin could be obtained in abundance. There appears to be no reason for doubting that the Phœnicians established themselves in Cyprus, and in that island manufactured bronze and brass. "The inventor," says Kenrick,† "of the manufacture of brass—of the tongs, the hammer, the lever, and the anvil —who gave to Agamemnon the breastplate of steel, gold, and tin, was a king of Byblus, who migrated thence and founded Paphos. The ore 'calamine' (carbonate, or silicate of zinc), which furnishes the ingredient for the manufacture of brass, and which was found in great abundance in Cyprus, as well as copper ore, was called cadmia." This statement of the abundance of zinc ore in Cyprus is open to correction. "Nowhere," continues Kenrick, "in the ancient world were mining operations carried on upon a larger scale or by more scientific methods than in Spain. . . . From the accounts of Posidonius, whom Strabo, Diodorus, and Pliny follow, it is evident that in the last century before the birth of Christ, mining works were carried on there with stupendous labour, and the application of the

* "The Cassiterides: an Inquiry into the Commercial Operations of the Phœnicians in Western Europe, with particular reference to the British Tin Trade." By George Smith, LL.D., F.A.S. 1863.
† "Phœnicia," p. 260. By John Kenrick, M.A. 1855.

best science of the age.* The author then, drawing evidently on his imagination, describes mining works as extensive and as skilfully arranged, as any that are to be found in the present day in any part of the world. Suffice it to say, that the relics of ancient works which are still discoverable in Spain, are invariably of the same rude character as those which we meet with in these islands.

A few words on the origin of the Phœnicians may serve to place the question under consideration in a more satisfactory light. The Phœnicians seem first to have come from the sea of Erythra, which includes the Indian Ocean, the Red Sea, and the Persian Gulf. They were driven from their native land by an earthquake. They settled first on the Assyrian lake and subsequently on the sea shore, founding the city of Sidon,* which was built when Abraham lived in Canaan.† The Phœnicians were a branch of the great Semitic or Aramæan family of nations, and they were nearly allied to the Jews in the time of Solomon, their language closely resembling the Hebrew.‡ In the days of Sardanapalus, the chief Phœnician cities paid tribute to that conqueror, and Sennacherib crossed the Euphrates and received the submission of Syria and Phœnicia.§ The Phœnicians are also said to have been emigrants of a serpent-worshipping tribe who came from a district in Afghanistan. They were a more ancient people than the Jews with whom they traded, but they were never conquered by them.‖

Posidonius, Strabo, Diodorus, and other writers appear satisfied that the Phœnicians established themselves in Spain, and that they made Gadez (Cadiz) a port in the early days of their occupation. Twelve centuries before Christ, has been assigned by some authors, as the date of their occupation. The geographical position of this port renders it a place of considerable importance to our inquiry, as from it a maritime people would certainly, in time, have reached Britain. Diodorus the Sicilian, writing only eight years before the birth of Christ, and consequently repeating what had been told by more ancient chroniclers, states that the Phœnicians undertook frequent voyages by sea, in the way of traffic as merchants; and that they established many colonies both in Africa and Western Europe, passing beyond the Pillars of Hercules, and building a city, Gades. This historian then informs his readers that a severe storm drove some Phœnician ships afar off into the main ocean, and that, driven before the tempest, they at length discovered the British Isles. The following passage from Diodorus demands especial attention:—

"We will now," he says, "give an account of the tin which is produced in Britain. The inhabitants of that extremity of Britain which is called Bolerion,¶ both excel in hospitality, and also, by reason of their intercourse with foreign merchants, are civilised in their mode of life. These prepare the tin, working very skilfully the earth which produces it. The ground is rocky, but it has in it earthy veins, the produce of which is brought down and melted and purified. Then when they have cast it into the form of cubes, they carry it to a certain island adjoining to Britain, and called *Iktis*.

* Kenrick's "Phœnicia."
† Phillip Smith's "Ancient History."
‡ "Penny Cyclopædia," art. Phœnicia.
§ Phillip Smith's "Ancient History."
‖ Kenrick's "Phœnicia."
¶ This term appears to have been exclusively applied to the district of the Land's End. See Milton.

During the recess of the tide the intervening space is left dry, and they carry over abundance of tin to this place in their carts. And it is something peculiar that happens to the islands in these parts lying between Europe and Britain; for at full tide, the intervening passage being overflowed, they appear islands, but when the sea retires a large space is left dry, and they are seen as peninsulas. From hence, then, the traders purchase the tin of the natives, and transport it into Gaul, and finally travelling through Gaul on foot, in about thirty days they bring their burdens on horses to the mouth of the river Rhone." *

The antiquity of bronze is generally admitted, although there is considerable diversity of opinion as to the period of the, hypothetical, Bronze Age; the probability being, that weapons and ornaments of this alloy were manufactured in the same ages by some people, when other races were engaged in making implements of flint. A Stone Age, and a Bronze Age, might, therefore, have been contemporaneous.†

Bronze and brass are frequently confounded: in old books the terms are used indifferently for the same metal. The former is made by the direct union of two metals—copper and tin—and the oldest metallurgists, discovered, by some empirical process, the true proportion for producing the hardest alloy. Brass was of very uncertain manufacture. Accident must have led some early metallurgists to the discovery that the red metal, copper, became yellow when it was melted in contact with a peculiar earth, *cadmia*—our calamine. Zinc was not known as a metal until 1509, when Erasmus Ebener separated it from the calamine of the furnaces at Rammelsberg.‡ The manufacturers of bronze and brass appear to have been, from a very early period, some branches of the Phœnician people, and the Assyrians. Probably some of the Jewish tribes were also skilled metallurgists. The copper for those alloys was obtained, it is tolerably certain, from Arabia and from Cyprus. The tin could only have been procured from India, from Spain—in which country it existed in small quantities—and from Britain, where in those days it must have existed in vast abundance, in the alluvial deposits, from which it was easily separated by the rudest process of washing. The black oxide of tin, when exposed to the heat of burning wood, melting very readily into a beautifully white metal, would soon attract the attention of the most untaught of men.

There has been much discussion on the terms used in the sacred writings and the old historians to signify tin: a few remarks will not therefore be out of place. Tin is named among other metals by Moses sixteen centuries before the Christian era; and Homer, who wrote eight centuries later (?), represents it to have been used at the siege of Troy, apparently in the eleventh century before Christ.

The Greek writers evidently knew that tin was obtained from the northern confines of Spain and Lusitania, and likewise from Britain; being brought overland through Gaul.

Roman writers at a later date, Pliny for example, give the name of

* Diodorus, lib. v.

† Thomas Wright "On the true Assignation of the Bronze Weapons supposed to indicate a Bronze Age in Western and Northern Europe."

‡ "History of Inventions, Discoveries, and Origins." By John Beckmann. Bohn's edit. 1846.

plumbum candidum to the *cassiteron* or tin of the Greeks; and he protests against the "fiction" of its having been obtained from any islands in the Atlantic Ocean, or anywhere but from Spain and Lusitania. The name of *stannum* he attributes to a metal which he describes as being intermixed with silver and *plumbum nigrum* (or lead).* Julius Cæsar,† a century later, wrote, "Nascitur ibi *plumbum album*," which many have supposed to be our tin. It is doubtful if Julius Cæsar intended tin. At all events he speaks of its being produced in the *inland* parts of Britain, which is true of lead, but not so of tin.

The Rev. Samuel Greathead writes: "The Latin term *stannum* appears to have been adopted from the ancient Cornish *stean*, or the Welsh *ystaen*, for which *plwm gwynn* (synonymous with *plumbum album*) is sometimes used."‡

Dr. Borlase, in his "Antiquities of Cornwall," deals with the whole question, and his remarks are, therefore, well worthy of attention, and their introduction in the accompanying notes requires no apology.§

* Pliny's "Natural History," lib. xxxiii. cap. 16, 17. † Cæsar's "Bell. Gall." v. 10.

‡ "On the Knowledge and Commerce of Tin among Ancient Nations." By the Rev. Samuel Greathead. ("Transactions of the Geological Society of Cornwall," vol. ii.)

§ EXTRACTS FROM BORLASE'S "ANTIQUITIES, HISTORICAL AND MONUMENTAL, OF THE COUNTY OF CORNWALL."

a. That the western parts of this island (viz. Devon and Cornwall) were first discovered by the Phœnicians, and by them inhabited, has no other foundation than that the names of places in these parts may be derived from Phœnician words, which is too deceitful a ground to build on, especially considering they may all be found in the British tongue, which, as spoke in the several extremities of the island (where the Phœnicians never traded), has great affinity with the Hebrew; and therefore we must take care how we attribute to the Phœnician traders names which may be found in our own British, a language derived in a great measure from the Hebrew, to which primarily the Phœnicians also owed their whole language.

b. There is another remarkable voyage of the Phœnicians mentioned in ancient history, but continued down to us with great uncertainties of circumstance and time.* Himilco was sent forth from Carthage to make a voyage to the north at the same time that Hanno, a Carthaginian, was dispatched the contrary way, to explore the southern coasts; but at what time those two leaders lived, whether a little before the second Punic war (as indeed the names seem to intimate), or much more anciently, in the time of Darius Nothus, is very undetermined, as Camden thinks, as also whether the Periplus of the latter, written in Punic, shall be of any authority, though, by Festus Avienus, affirmed to have been perused by him.

If the Phœnicians in their northern voyages coasted along the shores of Spain and Gaul (as was doubtless the most ancient way of navigating), then the shores of Britain opposite to Gaul must have been first known to them; but at whatever part of our island they first arrived, the western parts had certainly the greatest share of their commerce, if not the whole. The Phœnician business into these parts was not conquest and glory, but trade; and from Gades they traded to Britain, bringing salt, crockery, and brazen ware.† What they came for was tin, lead, and skins, but especially the former, which was soon found to be so useful a metal that it grew famous over all the then known world, and encouraged the Phœnicians to continue and engross the trade to this island.

But the principal inducement for the Phœnicians to frequent our coasts was tin, a metal far transcending both the beauty and the use of lead. This metal was anciently also found in Lusitania‡ and Gallicia, but in too small quantities to satisfy the expectations of so many cities and countries as were desirous to have it. The Phœnicians, therefore, having discovered abundance of tin in some small British islands, among which they probably reckoned the west of Cornwall, carried on so considerable a trade here, that from these little islands only they were enabled to supply the greatest part of the world with this useful metal. All the cities and nations of the Mediterranean had their tin chiefly from the Phœnicians, and they from the islands of Britain. I say chiefly, for though Spain yielded some little share of this commodity, yet it must have been a very small quantity, or the Phœnicians from Gades would doubtless have supplied themselves at home, and never have crossed the Atlantic Ocean at such hazard and expense in the infancy of navigation. This metal was not only sent up the Mediterranean, but exported even as far as India itself.

* Himilco's Voyage, p. 27. † Strabo, lib. iii. ‡ Portugal, Pliny, lib. xxxv, cap. 16.

The only districts in the continent of Europe producing tin, were Saxony, Bohemia, North-Western France, and Finland. The only countries from

Such an extensive trade required proportional supplies, and as we read of no tin mines worth notice east of the Dunmonii,* all the Phœnician trade for this metal must have been confined to that country now called by the two names of Devonshire and Cornwall, and the small islands adjacent to Cornwall, now Scilly (or Sylleh) Islands. Among these the islands were most productive, and therefore most famous in history; and from the tin they yielded, called *Cassiterides*. They were either named so by the Grecians,† from the Greek word, Κασσίτερον (Tin), or, it being confessed that both the Chaldeans and Arabians called tin by a name of like sound, so named by the Phœnicians themselves, which I must observe is so much the more probable, because we find these islands called Cassiterides long before the Grecians either traded thither or knew where the islands lay; for Herodotus, who lived about 440 years before our Saviour, says that he knew nothing of the islands Cassiterides, from whence their tin came.‡ Now, with great deference to Bochart's judgment, let it be observed that it is highly improbable the Greeks should give name to islands they knew not where to find, and consequently had no communication with, but through means of the Phœnicians. Solinus calls them Insulæ Silurum, or Insula Silura, of which the present name, Scilly, may seem to retain enough to justify him; but it is much to be suspected whether the ancient geographers knew the real situation of the Silures, and whether the Scilly Islands were not mistaken for islands adjacent and belonging to the true country of the Silures, or South Wales. However, if there be any truth in what Tacitus relates, viz. that the Silures were opposite to Spain, it can only be true of the Silures of the Scilly Islands; and if some of their inhabitants were like the Spaniards, it is not near so surprising as that the inhabitants of South Wales should be so. The inhabitants of Scilly have far more of the characteristics of the Spaniards than the people of South Wales. The Phœnician colony at Gades might probably send over some of their inhabitants to islands which afforded them so great a profit, in order the better to superintend and engross so profitable a commerce. Their descendants might retain, even to the time of Tacitus, the swarthy complexion and curled hair of the people they were sprung from. Here we find a resemblance which has history to support it, and no solecism in geography to weaken or reject it.

From these islands the Phœnicians had their treasures of tin,§ and were exceedingly jealous of their trade, and therefore so private and industrious to conceal it from others, that a Phœnician vessel, thinking itself pursued by a Roman, chose to run upon a shoal and suffer shipwreck, rather than discover the least track or path by which another nation might come in for their share of so beneficial a commerce.

c. Borlase supposed the Greeks to have visited Britain before Christ. They are thought by him to have passed through the Straits of Gibraltar as early as the time of Alexander the Great. Bochart ‖ says the Grecians did not come until 117 years before our Saviour. Pliny says that Britain was famous in Greek monuments long before the times of the Romans; and Polybius, a Greek by nation, who flourished about 200 years before our Saviour, though a constant companion of Scipio Africanus, promised to write of the British Isles and της κασσιτηρȣ κατασκευης (the methods of preparing tin), and made good his promise, as Strabo says, a task which so cautious a writer as Polybius would never have undertaken had there not been sufficient materials at that time to be procured for the groundwork of such an history.

d. I am sensible that the learned are of opinion that the Romans never came west of the river Tamar. All historians agree that the southern part of Europe was conquered by Claudius Cæsar. It is not unlikely that Cornwall, the southernmost part of all this island, may be included in this computation.

"Again, if we may conclude anything from the words of Tacitus,¶ 'Fert Britannia aurum et argentum et alia metalla prætium victoriæ,' we must think that the Romans made sure of the most considerable mines, as well as harbours, in Agricola's time, if not before. Again, Glaucus, in his celebrated speech, has these words, 'Neque sunt nobis arva, aut metalla,** aut portus, quibus exercendis reservemur;' intimating that the pasture, the metals, and the ports in other parts of the island had proved so many temptations to the avaricious Romans; but that there was no such thing in the country where they were."

e. What the ancient method was of preparing tin for the furnace we cannot say, but Polybius, the historian, is said to have described it, and that work is commended by Strabo, but now lost, with other valuable compositions of that judicious author. The short description which we have of the tin trade in Diodorus Siculus (lib. iv. p. 301, edit. Hanov. 1664) must not be omitted, though it is too general for us to learn many particulars from it.

"These men," says he, meaning the tinners, "manufacture their tin by working the grounds which produce it with great art. For though the land is rocky it has soft veins of earth running through it, in

* Cornish men, Cornwall comprehending Devon and Cornwall. † Bochart, p. 650
‡ Ουτε νησȣς οιδα Κασσιτεριδας εȣσας εκ των ὁ κασσιτερος ἡμιν φοιτα. In Herod.
§ Strabo, lib. iii. De Cassiter. ‖ See Diod. Sic. lib. v. p. 650.
¶ Tacitus, "Vit. Agric." ** Tacitus, Ibid.

which the Phœnicians could have obtained this metal, were Spain and England; all the other places being too remotely inland, and it is questionable if any considerable quantity of tin was procurable from any of them in those days.* Sir George Cornewall Lewis† says Gadeira or Gades was an ancient foundation of the Phœnicians of Tyre. "The foundation of Gades is placed by Mela at the time of the siege of Troy," but this is probably a legend similar to that of Brutus colonising Britain. The Periplus of Scylax, composed about 340 B.C., however, mentions the colonies and factories of the Phœnicians and Carthaginians on the western coast of Iberia.

which the tinners find the treasure, extract, melt, and purify it. Then shaping it [by moulds] into a kind of cubical figure, they carry it off to a certain island lying near the British shore, which they call *Ictis*; for at the recess of the tide, the space betwixt the island and the main land being dry, the tinners embrace the opportunity, and carry their tin in carts, as fast as may be, over to the Ictis (or port), for it must be observed that the islands which lie betwixt the continent and Britain have this singularity, that when the tide is full they are real islands, but when the sea retires they are but so many peninsulas. From this island the merchants buy the tin of the natives and export it into Gaul; and, finally, through Gaul, by a journey of about thirty days, they bring it down on horses to the mouth of the Erydanus, meaning the Rhone." In this description it will naturally occur to the inquisitive reader to ask where this Ictis was to which the Cornish carried their smelted tin in carts, and there sold it to the merchants. I really cannot inform him, but by the Ictis here it is plain that the historian could not mean the Ictis, or Vectis, of the ancients (at present called the Isle of Wight), for he is speaking of the Britons of Cornwall; and, by the words, it should seem those of the most western parts, that is, those who live at the extreme end of Britain, called Belerium, find, dress, melt, carry, and sell their tin, &c. Now it would be absurd to think that these inhabitants should carry in carts their tin near two hundred miles (for so far distant is the Isle of Wight from them), when they had at least as good ports and harbours on their own shores as they could meet with there. Besides, these inhabitants are said, in the same paragraph, to have been more than ordinarily civilised by conversing with strangers and merchants. Those merchants, then, must have been very conversant with Cornwall, there trafficked for tin, that is, there bought, and thence exported the tin, or they could have no business there. Their residence would have been in some of the ports of Hampshire, and Cornwall could scarce have felt the influence of their manners, much less have been improved and civilised by them at that distance. Again, the Cornish, after the tin was melted, carried it at low water over to the Ictis in carts. This will by no means suit the situation of the Isle of Wight, which is, at least, two miles distant from the main land, and never, as far as we can learn, has been alternately an island and a peninsula, as the tide is in and out. The Ictis, therefore, here mentioned must lie somewhere near the coast of Cornwall, and must either have been a general name for any peninsula or creek, Ik being a common Cornish word denoting a cove, creek, or port of traffic.

* It is easier to determine the locality of the "land of tin" (Britain and the Scilly Isles) than that of the "amber coast," for it seems to me very improbable that the old Greek denominative κασσιτερος, which was in use even in the Homeric times, is to be derived from a stanniferous mountain in the south-west of Spain, called Mount Cassius, and which Avienus, who was well acquainted with the country, placed between Gaddir and the mouth of a small southern Ibernus (Ukert, "Georgr. der Griechen und Römer," Theil ii. Abth. i. s. 479).

Kassiteros is the ancient Indian Sanscrit word Kastira. *Zinu* in German, *den* in Icelandic, *tin* in English, and *tenn* in Swedish, is in the Malay and Javanese language *tinnah*; a similarity of sound which reminds us of that of the old German word *glessum* (the name given to transparent amber) to the modern "glas," glass. The names of articles of commerce pass from nation to nation, and become adopted into the most different languages. Through the intercourse which the Phœnicians, by means of their factories in the Persian Gulf, maintained with the east coast of India, the Sanscrit word *kastira*, expressing a most useful product of Further India, and still existing among the old Aramaic idioms in the Arabian word *kasdir*, became known to the Greeks even before Albion and the British Cassiterides had been visited (Aug. Wilh. v. Schlegel, in the Indischen Bibliothek, Bot. ii. s. 893; Benfeg, Indica, s. 807; Pott, etymol. Forschungen, Th. ii. s. 414; Lassen, indische Alterthumskunde, Bot. i. s. 239). A name often becomes an historical monument, and the etymological analysis of languages, which is sometimes ignorantly derided, is not without its fruit. The ancients were also acquainted with the existence of tin (one of the rarest metals on the globe) in the country of the Artabri and the Callaici, in the north-west part of the Iberian continent (Strabo, lib. iii. p. 147, Plin. xxxiv. c. 16), nearer of access, therefore, for navigators from the Mediterranean than the Cassiterides (Æstrymides of Avienus). When I was in Galicia in 1799, before embarking for the Canaries, mining operations were still carried on, on a very poor scale, in the granitic mountains. (See my Rel. Hist. t. i. pp. 51 and 53.) The occurrence of tin in this locality is of some geological importance on account of the former connection of Galicia, the peninsula of Brittany, and Cornwall.—*Note to Humboldt's "Cosmos," vol. ii. note* 129, *Sabine's translation.*

† "An Historical Survey of the Astronomy of the Ancients," p. 449. By the Right Hon. Sir George Cornewall Lewis.

From Gades the adventurous Tyrians are thought to have steered their ships along the coasts of Spain, in search of amber, which was in great request, and tin. Eventually they reached the British islands, and were rewarded for their enterprise, by the discovery of a land rich in the metal for which they sought.

"It cannot be doubted," says Lewis, "that Britain was the country from which the tin sold by the Phœnicians to the Greeks was *chiefly procured.*" Herodotus had heard of the Tin Islands—the Cassiterides—but he was unable to obtain any information as to their situation. He says: "Of that part of Europe nearest the west I am not able to speak with decision. . . . I have endeavoured, but without success, to meet with some one who from ocular observation might describe to me the sea which lies in that part of Europe. It is nevertheless certain that both our tin and amber are brought from those extreme regions."*

The islands of Scilly have been fixed on by almost all old writers as the Tin Islands of the Phœnicians, and this, notwithstanding the fact that no tin is now discoverable in them. Dr. Borlase, evidently feeling the difficulty which exists in the endeavour to prove that the Scilly Islands were the Cassiterides of the ancients, supports the hypothesis that the sea has been continually disturbing the low lands in which detrital tin would have been found. He writes:†—

"The sea is perpetually preying upon these little islands, and leaves nothing where it can reach but the skeleton, the bared rock. . . . Many hedges now under water, and flats which stretch from one island to another, are plain evidences of a former union subsisting between these now distinct islands. History speaks the same truth. 'The isles of Cassiterides,' says Strabo,‡ are ten in number, close to one another: one of them is deserted and unpeopled, the rest are inhabited.' But see how the sea has multiplied these islands: there are now reckoned more than one hundred and forty, into so many fragments are they divided." After mentioning several phenomena which indicate submergence, Borlase writes again: "Tin mines they certainly had in these islands two hundred years before Christ. What is become of the mines? for the mines at present to be seen show no marks of their being ancient." In support of the view that considerable alterations have occurred in the relative position of land and sea, he quotes the following statement from Heath:§ "A person taking a survey of the channel in the year 1742, took one of his stations at low water, as he told me, upon this rock (viz. the Gulph Rock, midway between Penzance and Scilly), where he observed a cavity like a brewer's copper, with rubbish at the bottom, without being able to assign a cause for its coming there." The rock alluded to is the Wolf Rock of the present day, upon which a lighthouse now stands, an example of structural engineering of the highest class. "This," says Borlase, "could be no other than a rock basin, and consequently this rock is greatly sunk—by being now entirely covered with the sea—at least nine hours in twelve." This remarkable rock is of igneous origin, and it stands, a bold mass, in the deepest part of the channel, showing no indication of any alteration. The rock is a "phono-

* Herodotus's "Thalia," cxv.

† "Ancient and Present State of the Scilly Islands," p. 90.

‡ Strabo's "Rerum Geographicarum," lib. iii.

§ Heath's "Account of the Scilly Islands," p. 157.

lite, which occurs occasionally in the form of lava flows, but more commonly in conical masses or hills. It sometimes exhibits well-marked columnar structure." * The Wolf Rock has been usually considered as the solitary example in this country of this class of rock formation. A careful examination of the rocks along the coast from Cape Cornwall to Sennen, leads to the belief that examples of the same mineral formation are to be discovered in these cliffs. In many places, especially near Cape Cornwall, the columnar structure of Basaltic rocks is well marked.

After discoursing in his own unsatisfactory way of the alterations in the level of the land and the depredations of the sea, Borlase says:—"I conclude, therefore, that these islands have undergone some great catastrophe, and besides the apparent diminution of their islets by sea and tempest, must have suffered greatly by a subsidence of the land (the common consequence of earthquakes), attended by a sudden inundation in those parts where the above-mentioned ruins, fences, *mines*, and other things, of which we have no vestiges now remaining, formerly stood."

That a great inundation occurred, probably about the year 1014, appears proved by the submerged forests seen in the Mount's Bay, near Penzance, and several other places. The Saxon Chronicle gives this account: "Hoc item anno in vigiliis Sancti Michaelis contigit magna ista maris inundatio per latam hanc terram quæ longius expatiata, quam antea unquam, demersit multa oppida et hominum numerum inenarrabilem."

The legendary story of the flood which separated the Scilly Islands from the Land's End may be dismissed from consideration. Indeed, the inundation mentioned in the Saxon Chronicle is no doubt an exaggerated description of a small phenomenon. The same geological changes which separated Britain from the Continent produced, there can be but little doubt, the isolation of Scilly, at a period long before the existence of man in these islands.†

When the stream works of the Cornish tinners come to be described it will be rendered evident, that the detrital deposits are clearly indicative of the wearing down of extensive tracts of country, and it will also be shown that there has been more than one alteration in the relative levels of the sea and land. It is therefore within the limits of possibility that stanniferous deposits which once existed in the isles of Scilly may have suffered submergence, or have been washed away. The rise and fall of the tides certainly produce the phenomena of changing a promontory into an island, and the contrary, but not to the extent required by the narrative of the ancient historians. But there exists the difficulty that scarcely any remains of mine-workings are to be found in any of these islands, neither do any of the streams, or the foreshores, now yield detrital tin.

In relation to the only trace of mines in the Scilly Islands, Dr. Borlase writes: "On these downs we saw a large opening made in the ground, and dug about the depth of a common stone quarry, and in the same shape. There are several such in the parish of St. Just, Cornwall, where they are called 'Koffens,' and show that the more ancient way of mining was to

* "The Study of the Rocks." By Frank Rutley, F.G.S. 1879.

† See "The Geological Influences which have effected British History." By Archibald Geikie, F.R.S. "Macmillan," No. 269, March, 1882. Consult also "Les Mouvements du Sol sur les Côtes Occidentales de la France." By Alexandre Chèvremont.

search for metals in the same way as we at present raise stones out of quarries, which, as the metals bear no proportion to the strata of stone in which they lie, must have been very tedious and expensive. A little farther we found a row of shallow tin-pits, none appearing to be more than four fathoms deep, most of them no deeper than what the tinners call *costean* shafts, which are only six or eight feet perpendicular: to the west end of these pits there is the mouth of a drain or adit. This course of tin bears east and west nearly, as our lodes, or tin veins, do in Cornwall. These are the only tin-pits which we saw, or are anywhere to be seen, as we were informed, in these islands." *

In another page Borlase says: "I saw one vein at Trescaw mentioned before. It might be two feet wide, on a cliff near a place called the 'Gun-well.' There was a narrow one on the same island under Oliver's Battery. The former had been worked for tin, and has several shafts and burrows in the course of it, the only ones in Scilly; the other we could perceive no metal in." †

This statement of the existence of tin in Scilly has been greatly strengthened by a precise statement of Whitaker, who asserts, in his "History of Manchester": "In the month of May, 1767, a rich vein of tin was discovered in St. Mary's, *I think*, which bore directly into the sea and pointed towards the shore of Cornwall." It must not be forgotten that Borlase was, for twenty-four years the vicar of the mining parish of St. Just, and that Whitaker was resident rector of Ruan Lanyhorne twelve years after the date named in his book. It would be rash, therefore, to pronounce dogmatically that tin had not been found in Scilly, in the face of such statements, but certain it is, that the quantity of that metal obtained from these islands must have been exceedingly small. Cooley ‡ gets rid of the whole question by saying, "The name *Cassiterides* is evidently but an epithet." Heath, in his "Islands of Scilly," states that the inhabitants "had mines of tin and lead, which commodities they used to barter with merchants for earthen vessels, salt, and instruments of brass." The same author again states, "The lead was first brought from these islands into Greece by Madacritas." This is the only mention made of lead, and, examining the geological conditions of the islands, there are reasons for believing Heath to have been deceived in this. He gives a rather long description of the methods of working the tin streams and mines, but this applies more readily to the mining works on the main land of Cornwall than to the islands of Scilly. § Sir G. C. Lewis, endeavouring to support his views, quotes the Periplus of Hanno, and the "Ora Maritima," by Avienus, in which is recorded the discoveries of Himilco, giving them the date of about 470 B.C. "The report of Himilco was that the voyage from Gades to the Tin Islands (*i.e.* to Cornwall) occupied at least four months, and that the navigation in these remote waters was impeded by the motionless air, by the abundance of

* "Observations on the Ancient and Present State of the Islands of Scilly, and their importance to the Trade of Great Britain," p. 45. In a Letter to the Reverend Charles Lyttelton, LL.D., Dean of Exeter and F.R.S. By William Borlase, M.A., F.R.S. (1756). † Ibid. p. 72.

‡ "History of Maritime and Inland Discovery."

§ "A Natural and Historical Account of the Islands of Scilly, and a General Account of Cornwall." By Robert Heath, an officer of his Majesty's service, some time in garrison at Scilly 1750.

seaweed, and by the monsters of the deep." After this quotation it is not necessary to dwell any longer on the traditions and fables connected with Scilly.

Nearly all the modern writers who have written on this subject are disposed to regard the south-western promontory of Britain as the Cassiterides. In the imperfect state of the geography of those early days, the configuration of the land of Cornwall was such, that, from the sea, it might be readily mistaken for a group of islands. The Iktis of Diodorus—likely to be St. Michael's Mount—being used as a port, from which tin was shipped, became prominently marked as one of them. Diodorus speaks of other islands, which were, according to the time of the tide, approachable from the shore as peninsulas. There are several small insular masses which, no doubt, at one time answered to this description. St. Nicholas's or

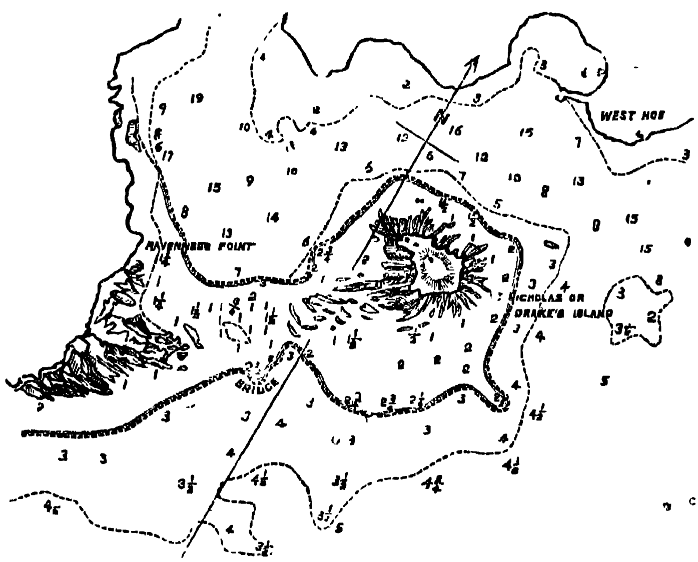


Fig. 1.—The "Bridge" in Plymouth Sound.

Drake's Island, Plymouth Sound, is one of them. This is now separated from Mount Edgecumbe by a ridge of rocks. The accompanying sketch from the Admiralty Chart of Plymouth Sound, Fig. 1, shows the actual soundings over the marked area known as the "Bridge," and beyond it. Across the space supposed to have been the original connecting link, it will be seen there is, between the exposed rocks on either side, at low water, a depth of one fathom only, the greatest depth within the marked area being 2¾ fathoms, while beyond it, on the northern side, we obtain soundings of from 14 fathoms to 19 fathoms. It is evident that the addition of but a small accumulation of soil, or rocky débris, would render this "bridge" passable at low tides. Loo Island is another example of the same kind. At very low water it was not unusual for men to pass across the connecting ridge. There are also places, now peninsulas, which were evidently at one period insular patches. "The Island" at St. Ives was one of those: the narrow neck of detrital matter connecting the island with the town is of comparatively recent formation. Pendennis

Castle, at Falmouth, is probably another example of the same kind; and others, smaller examples, but still giving evidence of man's labours upon them, as the Chapel Rock at Perran-porth, might be named.

The following passages give the popular notion, as stated by nearly all the older local historians, of the great changes which have led to the submergence of the Mount's Bay *:—

"Of the time and manner of these catastrophes there is no record, a circumstance remarkable, if, as supposed by some, they happened after Christianity prevailed and monkish establishments were formed in this part of Great Britain. All the historians of this county, from Leland, Norden, and Carew, downward, have noticed the ancient tradition of St. Michael's Mount being formerly situate in a wood several miles from the sea. They have also handed down as a concurrent tradition, according to Carew, who, treating of the ancient extent of the county, says: 'The encroaching sea hath ravined from it the whole country of Lionnesse, together with divers other parcels of no little circuit; and that such a Lionnesse was there, these proofs are yet remaining. The space between the Land's End and the isles of Scilly, being about thirty miles, to this day retaineth that name in Cornish, *Lethowsow*, and carrieth an equal depth of forty or sixty fathoms (a thing not usual in the sea's proper dominion), save that, about midway, there lieth a rock, which at low water discovereth its head. They term it the 'Gulf' (now known as the 'Wolf'), suiting thereby the other name of Scilla. Fishermen also, casting their hooks thereabouts, have drawn up pieces of doors and windows' (Carew, p. 3). To this Dr. Borlase ('Letters on the Scilly Islands') adds: 'That there existed formerly such a country as the Lionnesse, stretching from the Land's End to the Scilly Islands, is much talked of in our parts. Some fishermen also have insisted that, in the channel between the islands of Scilly and the Land's End, there are to be seen tops of houses and other remains of habitations.' Borlase, however, seemed desirous of showing that he put no implicit faith in the story, by adding: 'But I produce these arguments only as proofs of the tradition, and of the strong persuasion which from time immemorial has prevailed among the inhabitants of Cornwall, that such a country as Lionnesse once existed, but is now buried under the sea.' Though it must be acknowledged that, two pages after, the venerable and learned historian appears to credit the story, which then touched a string that vibrated very powerfully on a favourite theory, viz. the rock idols and rock sacrificial basins of the Druids."

It is possible that, either by the direct action of the ocean upon a low-lying tract of land, which is supposed to have connected the islands of Scilly with the main shore, or by the sinking of the land itself, the channel which now rolls between the Land's End and the islands might have been formed.†

The conclusion to which I have arrived—after a most careful examination

* "Geological Transactions of Cornwall," vol. ii. Mr. Boase "On the Submersion of the Mount's Bay."

† St. Michael's Mount. Mr. Jenkins, quoting Halse, says: "Contiguous to this parish or within the jurisdiction thereof stands St. Michael's Mount, in the Kernawish tongue *St. Mighele's Menyth*, so called for that the Britons, our ancestors, apprehended the appearance of the Archangel St. Michael about the year of our Lord 495 to be on this place, though the Italians say it was upon Mount *Garganus* in their country, and the Frenchmen tell us it was upon their Mount St. Michel in Normandy. About the time of the appearance of this angel the Mount was called *Dinsele* or *Dynsule*, as appears from the history of Llandaff church, which Mr. Camden, before me, hath well observed ('Camden Britannica,' p. 6.),

of the stanniferous regions of Cornwall, spread over many years—is that the inhabitants, whether Belgæ or an aboriginal people, discovered in the beds of rivers running through the valleys, and often subject to floods, a remarkably heavy stone (oxide of tin, or black tin), which they found would give them, by the action of fire, a beautifully white metal. Tradition says, the Cornish first made fish-hooks and rings of this metal; but, be that as it may, strangers, by some accident visiting their lands, discovered them in possession of a metal which, to them, was of the greatest value in the production of an important alloy. It will be readily understood that the foreign traders were anxious to discover the sources of this metal—tin—and that the natives were especially desirous of preserving this a secret to themselves. The result was, that the tin grounds were generally surrounded by extended earthworks. An example of these still remains in the "Bolster," at St. Agnes, a well-made earth mound, with a deep trench, which extends from Chapel Porth to Trevaunance, a distance of two miles, completely enclosing the hill known as the "Beacon," and the important tin district around it. We have, again, at St. Ives the remains of a remarkable Cyclopean stonework, with here and there indications of rude buildings, evidently places of defence, or storehouses. This extends from near Tregenna to the rough promontory of Clodgy. Other examples might be adduced of the value placed by the natives on the produce of their "tin-streams" and shallow mines. In their desire to secure themselves from their, probably, piratical customers, there is no doubt they arranged that the traffic in tin should be confined to islands near the shores. At St. Michael's Mount would be collected the tin produce of all the district, from Marazion to St. Ives, and then to the Land's End, and the fact of the sale of tin on this spot, to the Phœnicians, appears preserved in the name of Market-Jew, which is commonly given to the first-named town.

Thucydides has a passage, which seems to refer those insular tin-markets to the desire of the Phœnicians, to secure for their own purposes, certain convenient tracts for the shipment of their collected treasures. "The Phœnicians, likewise, had settlements all round the coasts of Sicily. *They secured the capes on the sea*, and the small adjacent islands, for the purpose of trafficking with the natives."* If they did so in Sicily, are they not likely to have followed the same course in Cornwall?

Mr. John Hawkins, F.R.S., in writing "On the Changes which appear to have taken place in the Primitive Form of the Cornish Peninsula,"† says, with special reference to the Scilly Islands and the Mount's Bay: "Secondary changes are the natural result of the present constitution of our atmosphere, and they are consequently familiar to our notice. A changeable temperature, constant humidity, the combined forces of wind and rain, the electric fluid, the action of violent floods, even the silent force of vegetation, and, lastly, the heavy swell and the boisterous surge of the Atlantic, have evidently wrought great changes in the form of our peninsula. The naked summits of our moorstone

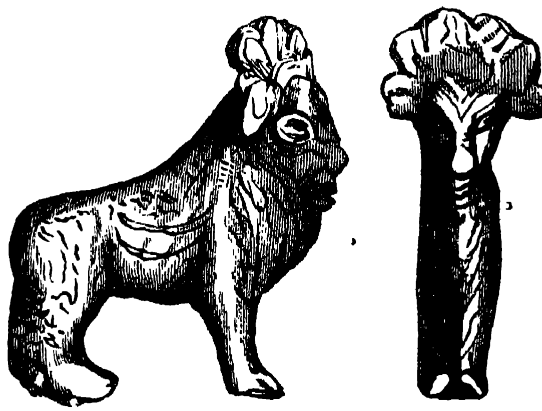
though he did not understand what those names imported, both being *Kernawish*, the first compounded of *Din-sile*, *Mass Sunday*, the second, *Din-sule*, *Mass Sabbath*. I take it to signify 'The hill in open view,' from '*sele*,' a view or prospect."

* Thucydides, lib. vii.

† "Transactions of the Royal Geological Society of Cornwall," vol. iii. 1829.

hills bear witness to the influence of the causes here enumerated; nor can the solid rampart of rocks which is opposed to the western ocean wholly resist the constant impulse of its waves. . . . . In length of time, the cliffs so exposed to the fury of the waves are undermined, and not unfrequently immense masses of rock are detached by their own weight from the higher levels. The long reaches of rocks which are exposed at low water mark the extent of these depredations, and the rocky islets which range along the coast must be regarded as the wrecks of some advanced portion of high land. Even the Mount, that noble ornament of our coast, must be placed by the geologist in this class of phenomena." I have preferred to quote so good an authority as Mr. J. Hawkins on this subject, explaining, as his words do, the formation of the "Bridge" in Plymouth Sound and other similar phenomena, which will be further noticed when we come to consider the mineral deposits. It should, however, be noted here that a regular survey of the date of Edward IV. is often appealed to, to show that the county of Cornwall contained then twice the number of acres that are now found in it.

It will naturally be supposed that the Phœnicians, if they held possession of any part of Cornwall, would have left memorials of their presence. These are, however, exceedingly rare. In the Museum of the Royal Institution of Cornwall, at Truro, is a small bronze casting of a bull, about two inches in height, which has many of the distinguishing features of the Assyrian bronzes, Fig. 2. This was found in St. Just. A similar figure has been found in Babylon.* Mr. R. S. Poole observes, "It is precisely what a Phœnician trader would have carried; an idol common no doubt to Egypt and Phœnicia."† Mr. Allen, in his history of Liskeard, informs us that, in 1853, a curious image, about two feet high, made of tin, and representing a man, was found nine feet beneath the ground in a "Jew's house," or stream-work, in Lanlivery parish. It weighed 9 lbs., and had some Hebrew initials on it.



2.—Bronze Image found in St. Just.

Bronze instruments usually termed celts, rings of the same metal, formed to go round the wrists, together with swords of a peculiar construction, have been found in the alluvial deposits and in peat-bogs, of Cornwall. It may be thought by many that those belonged to the Romans; but Professor Rawlinson says, "The bronze swords, daggers, and spear-heads, which have neither a Greek nor a Roman type, were probably first introduced by the Phœnician trade."‡

* Waring's "Monuments, &c., of a Remote Age." London, 1870. Pl. cvii. p. 84.
† "Report and Journal of the Royal Institution of Cornwall."
‡ Rawlinson's "Herodotus," edit. 1862, p. 317.

Mr. W. C. Borlase writes: "Spear-heads have occurred in St. Hilary and St. Erth, and in the stream-works of Pentewan and Roach. Celts have occurred near St. Michael's Mount; in St. Hilary, at Godolphin mine, and in the stream-works of Treloy, Carnon-Leat, and elsewhere. We may add a bronze fibula and an object of jet from Pentewan, a bronze pin with a leaden head from St. Colomb, and a bronze and amber implement from Fowey, all in connection with mining operations."*

A remarkable discovery was made at the mouth of the stream which forms the western boundary of the town of Marazion. It is thus described by Mr. Richard Edmonds.† "In 1849 the stream, having been diverted, flowed westward along the base of the adjoining sand hillock, undermining and washing away large portions. In sections thus made, I saw, at the depth of between three and six yards beneath the surface, the remains of ancient walls, rudely built of unhewn stones, with clay, and near them great quantities of ashes, charcoal, and slag, besides some ancient broken pottery of very rude manufacture, and much brick. In removing a portion of the sand within a few inches of one of the walls, my nephew (Frederic Bernard Edmonds) and myself, discovered two fragments of a bronze vessel resting on charcoal, a considerable portion of which had combined with the copper during the lapse of ages, and a beautiful green substance had resulted—the carbonate of copper. The fragments were each about six inches long, four wide, and only the sixteenth of an inch thick, having been apparently parts of the circular top of a vessel three feet in diameter, the mouth being bent back into a horizontal rim three-quarters of an inch broad. No charcoal was on the insides of the fragments, but their outsides were completely blackened and covered with it.

"Professor Hunt, at whose request I presented one of the fragments to the Museum of Economic Geology, kindly analysed a small portion, the following being the result:—

"Weight before analysis, 25 grains.	Grains.
Copper	18·0
Tin	2·25
Iron	1·0
Loss as carbonic acid and oxygen, the copper being partially in the state of carbonate, and much of the tin in oxide	3·0
Earthy matter	0·75
	25·

"These very ancient ruins, therefore, with the fragments of a bronze bowl, and the abundance of ashes, charcoal, and slag, all covered with the sand of many centuries, seem to indicate the very spot where, as Diodorus relates, the tin was cast in cubic forms, previous to its conveyance in carts to the neighbouring island during the recesses of the tide.

"The bronze vessel was, I conclude, brought hither by the Phœnicians, for no copper was then raised in Cornwall; and Strabo mentions that the Phœnicians furnished us with earthenware, salt, and copper or bronze

* "Historical Sketch of the Tin Trade in Cornwall, from the earliest Period to the present Day." By W. C. Borlase. Plymouth: 1874.

† "The Land's End District: its Antiquities, Natural History," &c. By Richard Edmonds. 1862.

eighth year, to concert their common interests and regulate their proceedings, on Hingston Hill, near Callington. They were now divided, and formed distinct bodies. Five towns in Cornwall and three in Devonshire were named, where the tin ore was taken for "Coinage." That is, the blocks of metal were there stamped, and a portion from each was retained for the King or his representatives. These were called coinage towns. Each tinner was now permitted to sell his own tin, unless the King insisted on buying it.

The charter of John (A.D. 1201) was confirmed in the thirty-third year of Edward I. (A.D. 1305),* and the tinners of Cornwall and Devon acted under new and improved laws. These charters (*pro Stannatoribus in comitatu Cornubiæ*) are preserved in the Rolls in the Record Office, and they are given, in facsimile, in De la Beche's Report already quoted. The original of the charter of Edward was kept in Luxullion Church, whence for greater security it was removed to Lostwithiel during the civil wars, and was there destroyed by the army of Essex in 1644.†

In the eleventh year of Edward III. (1337), we learn from a charter roll, preserved in the Record Office, of "The grant to Edward, Duke of Cornwall and Earl of Chester, the King's son, of the Sheriffalty, and divers castles, manors, &c., in Cornwall and Devon, declaring his creation to the Dukedom."

After reciting that, with the unanimous assent and advice of our present Parliament, &c. &c., we have "given to our said son the name and honour of Duke of Cornwall, and have created him Duke of Cornwall, and have girt him with a sword," &c. &c.; the castles, manors, &c., granted by the charter, are then enumerated, and it proceeds:—

"Also our Stannary in the same county of Cornwall, together with the coinage of the same Stannary, and with all the issues and profits thereof arising. And also the explees, profits, and perquisites of the Stannary and mine courts in the same county, except only one thousand marks, which we have granted, for us and our heirs, to our beloved and faithful William de Montacute, Earl of Salisbury, to be received by him and the heirs male of his body lawfully begotten, from the issues and profits of the coinage aforesaid, under a certain form in our other charter, to the same Duke thereof, made more fully declared, &c. &c. &c. Given by our hand, at Westminster, the eighteenth day of March, 1337. By the King himself and the whole Council in full Parliament."

After the exile of the Jews, the mines were for a long period neglected. Probably this people had taken the tin streams and shallow mines into their own charge, and when they were driven from them, there were but few men left capable of working them. The tin deposits in Cornwall were at

* Edward I.—for the advancement of the Stannaries of Cornwall—frees the Tinners from all pleas of the Natives touching the Court, and from answering before any justices, &c., concerning the Stannaries, save only the Keeper of the Stannaries. Indemnifies them from Tolls. Gives them leave to dig Tin and Turf anywhere in the said County; and to turn Water-courses for their works at pleasure.

Edward III.—Indenture, dated 11th July, Anno 32, grants unto John Ballanter and Walter Bolbolter all his Mines of Gold, Silver, and Copper, in the County of Devon, for two years, with libertie to dig and search (except in Gardens yielding 20 marks the first year, and the fifth part the second year), and all other persons are excluded from digging there.—*Sir John Pettus*, "*Fodinæ Regales.*"

† According to a MS. of the time of Elizabeth, entitled "The Bailiff of Blackmore."

this time entirely in the hands of the King, and for the purpose of increasing his own revenues, he granted many privileges to the new adventurers, as Tinners. In 1240 Cornwall is said to have supplied all Europe with tin.

Carew, in his "Survey of Cornwall," writing from information obtained from "Master William Carnsew," who had seen John's charter, says: "After this it happened that certain gentlemen, being lords of seven tithings in Blackmore, whose grounds were best stored with this mineral (tin), grew desirous to renew this benefit; and so upon suit made to Edmund, Earl of Cornwall, sonne to Richard, King of the Romans, they obtained from him a charter with sundrie privileges, amongst which it was granted them to keepe a court, and hold plea of all actions (life, lymme, and land excepted), in consideration whereof the sayd lords accorded to pay the earle a halfpenny for every pound of tynne which should be wrought, and that for better answering this tax, the said tynne should bee brought to certayne places purposely appointed, and there prized, coyned, and kept, until the earle's dues were satisfied. Again, the lords of these tithings were there allotted unto them the tole-tynne within those tithings, which their successors do yet enjoy. This charter was to be kept in one of the church steeples within those tithings—and the seale had a pickaxe and shovele in saultier graven thereon."

Wrotham, in his capacity of Warden of the Stannaries, established new laws, which secured much freedom to the tinners. He, however, made certain regulations which were mainly to enforce the King's-right, and to increase the toll on tin. The liberties which John's charter ensured to the tinners were, that "they should be quit of all pleas of serfdom," because "the Stannaries are our royal demesne." The tinners were, "without hindrance from any man, at all time to freely dig tin, and turves to melt it, anywhere in the moors and in the fees of bishops, abbots, and earls, and should buy wood for the melting, and divert watercourses for their works, as by ancient custom they had been used to do." Again: "They should not be compelled to leave work at the summons of any man but that of the chief warden or his bailiff."

It is evident that, at the time of Wrotham, the Jews still held possession of many of the mines in Cornwall. He continually speaks of "Christian nor Jew." In the names of the jurors contained in his regulations we find several Hebrew names. Professor Max Müller, in his "Chips from a German Workshop," informs us that in the third year of King John (1201), Simon de Dena, Dendone son of Samuel, and Roger Rabi affixed their names to Wrotham's document. Even after their banishment some Jews appear to have lingered behind. Roger le Jeu is named in the reign of Edward II., and Abraham the tinner, who employed three hundred men in the stream-works of Brodhok. In olden time the tinners of Cornwall and Devon held a meeting on Hingston Hill, near Callington, every seventh or eighth year, to arrange their common interests; but after the Regulations of the Warden Wrotham, Cornwall was separated from Devonshire. Five coinage towns—or places where the tin was carried to be tried (coined) and marked—a piece of tin being chipped off each slab as a royalty to the King or to the Duke of Cornwall—were fixed on for Cornwall and three for Devonshire. These

were Lostwithiel, Bodmynyan, Liskiriet, Treueru, and Helston for Cornwall and Tavystock, Asperton, and Chaggeford for Devonshire. The prisons of the Stannaries were fixed at Lostwithiel and Lydeford. According to Carew, these courts were not over remarkable for fair verdicts. The justice of Lydford is celebrated in a rude verse:—

> Who has not heard of Lydford Law,
> Where in the morn they hang or draw,
> And sit in judgment after.

The regulation of the Stannaries Court will not form the subject of consideration in this volume. The examination of the laws relating to mines and minerals would occupy much more space than can be afforded to this subject.

Pursuing our historical sketch, Edward II., about 1327, granted the Stannaries to his favourite, Gaveston, and in the tenth year of his reign (1336) he made over the coinage of tin to Stephen of Abyngdon, his butler, and John Pecoke, his valet. At this time the tinners in Cornwall numbered only 500, whereas but a few years previously they numbered 3,000. In 1337 a grant of the Stannaries was made to Edward the Black Prince, and we are told the coinage in that year amounted to 4,000 marks. In the following year the King, in the most capricious manner, seized all the tin produced, and for a considerable time tin-mining was at a very low ebb. It was not until 1376 that any measure of redress was sought for. In that year the tinners obtained the sanction of Parliament to the rules and regulations of the charter of Edward I. In the reign of Henry VII. (1489) the charters were declared void, but after several years of severe struggle the forfeiture was rescinded, and a free pardon granted to the miners.

In 1376 the tinners were able to obtain protection by Act of Parliament, but until the reign of Henry VII., when the Wars of the Roses were brought to an end, and England became more settled, the mines were almost entirely neglected.

Henry VIII. did but little to promote the mining industries of England. In 1509 Parliament passed an Act which decreed "that no person shall buy tin or any wares made of tin out of the realm." This appears to have resulted from the discovery of tin in Bohemia in 1240, and the subsequent discovery of tin mines at Altenburg, in Saxony, in 1458.

The Stannary parliament being allowed to frame their own laws, these laws continued active through the reigns of Henry VIII. and Edward VI. At Crockern-Tor, on Dartmoor, several parliaments were held, ninety-six "jurates" being appointed, twenty-four from each coinage town in Devon— "Chaggeford, Aysberton, Plymton, and Tavistocke." At these, and at other parliaments held at Lostwithiel and other Cornish courts, the weights and measures to be used were fixed, and numerous regulations as to the coinage of the tin were decided on. By these parliaments the tinners were allowed the right of free search on any man's ground for tin. This was carried to such an extent that no property was safe. Not only did the miners dig over the waste lands, but they entered upon cultivated grounds, they put down their pits in ornamental parks and in gardens. Eventually this evil was to a great extent removed by the introduction of a system of "*Bounding*." This was

ruled by the following custom: The tinner who desired to make a search must apply to the owner of the soil, and proceed with him to the spot he wished to work. There and then he should take him "by the arme and declare to him with a lowde voyce, that he may hear him—the cause of his pitch, and the day when he pitched the same tyn worke." A turf was cut at each corner of the ground selected, and regularly renewed by a person called a "Toller;" the owner of the soil receiving a fifteenth part, or "dish," of the black tin raised within the "bounds." Before the tinner could establish any right to those bounds, it was necessary that he should record his claim in the Stannary books; and, unless appealed against, he had thenceforth a just right to search for tin within such bounds as he had cut.

Pryce, in his "Mineralogia," gives us some important information as to the quantity of tin raised at different periods, including especially the period with which we have been dealing.

In 1471 the Duchy received, as profit, at 4s. per cwt.	£1,705	0	5
In 1479 the amount of the coinage dues for Cornwall was	£1,620	17	11
In 1524 the profits of Devon and Cornwall were	£2,771	3	9½
(424 tinners in Devon paying in addition to coinage dues 8d. per annum for *white* rent to the Duke.)			
In 1602 the tin coinage in Cornwall alone amounted to	£2,623	9	8

In 1558, and until 1603, Queen Elizabeth paid much attention to the British mines. She sent to Germany, and obtained the services of a large body of practical miners. These were dispersed over the various mining districts of the kingdom, and they introduced a better system of mining, and more perfect processes of dressing the ores. This was especially observable in the machinery employed for dressing the ores of tin and lead.

During the seventeenth century the average of metallic tin produced was, according to Pryce, 1,500 tons per annum. During the reign of Queen Anne there appears to have been a great accumulation of tin. A stock of 5,000 tons of tin, equal to five years' consumption, hung on the market, and a great deadness of trade continued until 1789, when the East India Company became speculators. The speculation answered, and the demand rose from 500 tons per annum to 15,000 tons, the price advancing at the same time.

This will be the proper place to describe briefly the system of Bounding, which was a peculiar feature of mining at one period, although now unknown.

Bounds were limited portions, or pieces of land, enjoyed by the owners of them in respect of *tin only*, and they were established by virtue of an ancient prescription, or liberty, for encouragement to the tin miners. They were limited by holes cut in the turf, and the soil turned back upon the turf, which is cut in form of a mole-hill, and directly facing another of the like kind. These are called the *corners of the Bounds*. By drawing straight lines from the corners, the extent of these Bounds is determined in like manner as, in geometry, by drawing straight lines from three, or sometimes four, points, the extent of a triangular or quadrangular superficies is known (*Pryce*).

The annexed plan of the North Downs Bounds (Fig. 8), as they existed formerly upon the site of, or near the North Downs mine of the present day, will convey a correct idea of the irregularity of the system of Bounding.

If the land is neither Bounded nor enclosed, but a *wastrell* or common, then any one could mark out Bounds there, and claim the search for tin. The Stannary Laws eventually insisted that "whoever intends to cut a Tin

Bound, must first give three months' notice of his intention in the Stannary Court, and to the lord, for him to show cause, if he is so inclined, why it should not be done."

It is exceedingly difficult to ascertain the exact time when Bounding was first commenced. Probably it arose from the necessity of each miner marking out his set, which was on the plan distinguished by the letters of the alphabet.

A Bounds book, dated on its vellum cover 1716, and labelled "Hussey's BOUNDS BOOK," having on its first page, "Mr. Francis Gregor's Book of his Tyn Bounds, made the 2nd of January by us, 17$\frac{15}{16}$, gives the

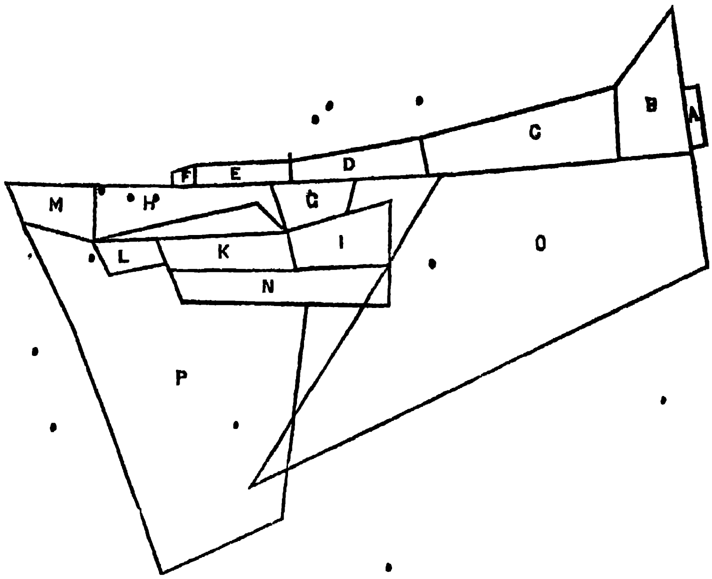


Fig. 9.—Plan of North Downs Tin-Bounds.

names and defines the situation of eighty-two Tin Bounds in St. Agnes and Pyran Sands," has been placed in the author's hands.

From this book the following first four Bounds only have been copied, as they will show very satisfactorily the irregular way in which those spots of tin ground were divided.

NAMES OF THE BOUNDS.	THEIR SITUATION AND BOUNDARIES IN ST. AGNES.
Speedwell.	In Polbreen Croft. Bounded on the South with Whealan-vor; on the East with a little piece of Sevorall; on the North with the Four and Twenty paire; and on the West with the little Whealan Culliack.
Good Fortune.	Bounded on the North with a little paire of Bounds belonging to Mr. Francis Gregor and others; on the East with Speedwell; on the South with the little Whealan Culliack; and on the West with Mr. Tonkin's Sevorall.
Preservation.	3 Bounded on the East with the little Whealan Culliack; on the West with Whealan Crack; on the North with Good Fortune; and on the South with Whealan Bolster.
Prevention.	4 Bounded on the North with Speedwell; on the East with Whealan-vor; on the South with the Great Whealan Culliack; and on the West with Preservation. Mr. Francis Gregor in those four paire of Bounds last mentioned have two-third parts, and Francis Bassett, Esqre., have the other third part, commonly called by the name of Polbreen Bounds.

The following grant of certain Tin Bounds is interesting, as showing that the descendants of Schutz, who was brought from Germany by Queen Elizabeth, attained to a place of honour, and kept it as late as 1740:—

"John Schutz, Esquire, Lord Keeper and Warden of the Stannaries, Chief Steward of the Duchy of Cornwall, and so forth, To the Bailiff of the Stannary of Tywarnhaile, in the County of Cornwall, and also to Christopher Oates, John Wills, and John Bawden, and every of the GREETING, Whereas Messrs. Perry to the court held for the said Stannary of Tywarnhaile, at Truro, within the said Stannary, the sixth day of October, in the fifteenth year of the reign of our Sovereign Lord George the Second, by the grace of God of Great Britain, France, and Ireland, King, Defender of the Faith, and so forth, and in the year of our Lord one thousand seven hundred and forty-one, Before Richard Hussey, gentleman, Steward of the said court, and gave notice to the said court, That he had on the twenty-third of September last past Cutt and paired one pair of Tin Mine Bounds (Void of all other lawful bounds) called Wheal Coynt Bounds, lying and being in the parish of St. Agnes, within the said Stannary, To the only use of James Donnithorne, gentleman, The South West Corner of the said Bounds, lying at the corner of Pitt's Hedge, joining with the corner of a mine croft or Wheal Burrow, and Great Truslee the North West corner thereof, for about one hundred yards south of Creegmore burrows, in the Downs. The North East corner lyes about thirty yards to the North East of Trufla shop joining with Great Trufla and Wheal Long, together with a North Side bound, or half corner between the North West corner and Creegmore Burrow aforesaid, and joining Wheal Burrow, containing about Ten Acres of Land, or ground, as by the Bounds and Limits thereof will more plainly appear." Proclamation of these Bounds is then prayed for, certain conditions are accepted, and the document duly signed.

"E. R. COOKE, Attorney." "R. HUSSEY."

(With an addition which is not intelligible.)

Another Deed, bearing date 1743, shows that THOMAS PITT, Esquire, was then "Lord Keeper and Warden of the Stannaries, and Chief Steward of the Duchy of Cornwall, and so forth." He issues "To the Bailiff of the Stannary of Tywarnhaile, and also to Christopher Oates, John Wills, David Jarba, and John Jarba"—forming the Court—his statement, "That Moses Perry came to the Court held for the said Stannary of Tywarnhaile, at Truro, within the said Stannary, &c. &c., Before Sampson Sandys, gentleman, Steward of the said court, and gave notice to the said court, That he had on the 18th day of July in the year of our Lord 1743, cutt and pitched one pair of Tin Mine Bounds (void of all other lawful Bounds) called or known by the name of Wheale Dower,"—one moiety or half of the said Tin Bounds, To the use of James Donnithorne—one quarter part to the use of Benjamin Nankivell the younger—and the other quarter part to the use of Anne Trezise and Mary Trezise. The Bound Boundaries are then stated in the usual manner, and certain covenants inserted, the document being signed by

SAMPSON SANDYS, Steward.

The endorsement states that this Writ has been duly delivered to those above mentioned; to whom the Tin Bounds have been granted.

The following has been copied from Mr. J. S. Enys's "Bounds Book." Kept by Henry Tregellas. Beginning in 1765.

"I, Henry Tregellas, agent for John Enys, Esq., grant asset unto James Martin of $\frac{8}{9}$ pts of a paire of Tyn Bounds, Called Wl Drible or Driblewill, and the Sd James Martin is to have Twenty fathom of Ground on the Course of the Load or Loads he shall work on Condition of paying one Twelfe part of all the Tyn he Shall Rise out of Sd pitch, at the Milting-house after the Toll is first payd, and to give Twenty-four owers Notice to the Agent Intrusted to go to Milting-house to Receve the Sd farm, but it is Farther agreed with the Sd Henry Tregellas & the Sd James Martin that it Shall and may be Lawfull for the Sd John Enys, Esq., or his agent at any time whenever they shall think proper to have the ninth pt powred, out on the grass, whereby he may have his pt of the farm in the Stone, and to Grant Liberty to the Agent to go Down Into Sd Mine, to Diel or measure the ground when Ever he Shall think proper, and to work the Sd Mine according to the Last act of Convocation, all which Above Conditions I the Sd Taker do agree to perform, as witness my hand this 25th Day of Feby, 1767,

"Henry Tregellas Letter,

"JAMES MARTIN."

The miners, in old times, appear to have enjoyed especial privileges: they could search for tin or copper in all waste grounds, or *Wasterall*, paying only a royalty to the Crown upon the ore they rose. In the "Bailiff of Blackmore,"—a manuscript of authority by Mr. Beare—one of the Stannators for Blackmore, we read: "That they," the tin miners, "always used to worke and search for tynn in *Wasterall* grounds, and also in the Prince's *Severall*, where any tynne might be gotten; having likewise libertye to digge, mine, search, make shafts, pitch bounds; and for tynne to work in places of their most advantages; excepting only sanctuary grounde, churchyards, mills, backhouses, and gardens; paying only to the prince or lord of the soil the fifteenth part to and for the toll of their tynn."

Mr. Gregor, a Vice-Warden of the Stannaries, states that he finds "that the tinners wrought for their tin by custom, until the 33rd of Edward I. (1305), which was sixty-four years after the Jews were banished, when they (the miners) procured their charter, which was obtained at the solicitation of the Lords of Trethuvy, Boswithy, Treverbyn, Prideaux, Trenans, Austell, Tremedry, Tregarrick, and Milliack, who obliged their lands to pay assent, and do service to the law courts erected by the charter."

We learn from Plowden, quoting "Pearce's Stannary Laws," and from Sir John Doddridge, that all tin was at first the possessionary right of him who had the government of the country, and from whom, or from the King, the liberty was granted immediately to the searcher.

Pryce remarks: "The first institution of those customary tenures, for the encouragement of searching for tin, was laudable and wise; but the late (he

is writing in 1778) increase of tin and discovery of lodes, together with the present improvements in mining, very much diminish the necessity of this kind of encouragement. On the contrary, from very good reasons, I can assert it would be well for this county in general if tin bounds were totally obliterated."

Bounds are no longer known. Bounding has no existence in modern times. A set of bounds for tin, though verbal, was perpetual, and never ended while it was wrought according to the laws and customs of the Stannaries. To preserve the right of a bounds, it was to be renewed once every year, which was performed in different bounds on different Saints' days, according to the parishes, by the servant of the lord, called the *Toller*, the *Renewer*, or the *Bounder*. The renewal consisted really in putting more earth upon the turf marking the original bounds, retiring to some house of entertainment and eating a good dinner, to celebrate and commemorate the annual renewing-day.

It was lawful for the bounder, or any other person to whom he had granted liberty, to dig and search for tin, provided that he acknowledged the lord's right by giving him a fifteenth part of the whole produce; then it was lawful for the bounder to take out one-twelfth, or in some places one-tenth, of the remainder.

Tinners were allowed to drive an *adit* for the passage of water only through other bounds without liberty; but if they discovered tin, that mineral was left wholly to the owners of the bounds within which it was found.

In 1697 a curious tract was published, from which we may glean some important information. It bears the title "Aggravii Venetiani," &c.; or, "The Venetian and other Grievances, together with a proposal for raising the price of tin in the Counties of Cornwall and Devon, according to the Policy of the *Venetians*, when they regained the Western Trade, which they had once almost lost. Most humbly presented to the King's Most Excellent Majesty (Charles I.), the Right Honourable the Lords Spiritual and Temporal.

"And to the Honourable the Commons of England in Parliament assembled, and humbly offered to the Honourable Council appointed to inspect the Trade of the Nation. London: Printed for Sam Crouch, in Cornhill; Abel Roper, in Fleet Street; and Joseph Fox, in Westminster Hall, in 1697."

This pamphlet deals chiefly with the sad difficulties which at the date mentioned—the beginning of the seventeenth century—surrounded the currant trade at Zante. Owing to the difficulties thrown in the way of this trade, smuggling to an enormous extent was carried on. With these matters we have nothing to do; but the second part, "The Proposal for raising the Price of Tin," &c., immediately concerns us. The author commences: "Had we, in the four last reigns, exemplified the policy of the wise Venetians to encourage and promote our trade and commerce, being posted by nature on *the emporium of the world*, and being a warlike people, what could we not have done? A well-managed trade is the creator and preserver of money, and money and trade are the sinews of war." He continues:—

"Cornwall (by the providence of God) doth naturally produce tin. A mettal, when fine, is in its nature next to silver, and is said to have given the name of *Brittain* to this nation; which being consider'd, may ingage the

King's most excellent Majesty, as God's representative, and his High Court of Parliament, to have the greater value and esteem for it.

"The county being environed as it is by the sea, and having the advantage of good harbors, Nature seems to have designed it for a flourishing trade; and the more, because that land not only abounds with the best tin in the world, and the greatest quantities thereof, but the sea affords it the best fish also.

"And abounding with tin and fish, as *Zant* doth with currants and wine, as the *Venetians* have improved the trade of *Zant*, so we should use our utmost endeavour to encourage and revive the trade of *Cornwall.*

"What prices tin bore, and what trades were driven thereby in Queen Elizabeth's time, when we had the absolute empire of the ocean and a flourishing trade, I cannot so well inform my reader as I would.

"But some years before the Restoration, when we had again the command of the seas, that commodity of Cornwall yielded to the tinners there £6 5s. a hundred merchants weight, clear of all coinage duties; and then the income to that county (by that commodity only) amounted to £200,000 a year and upwards.

"The quantities of tin are now almost the same as formerly, only that trade hath been, of latter years, mismanaged, to the great disadvantage both of that county and the kingdom, the price of tin being now brought down to 50s. per cent. or thereabouts. For the Cornish factors are less kind to their countrymen, the tinners, than our English factors are to the Zanteots; and more faithful to the London pewterers, than those are to their English principals. And (being no less careful for themselves) as our factors imploy their merchants' capitals, to prevent and forestall those that imploy them; so our Cornish factors imploy the stock, remitted to them by the pewterers, in necessary materials for carrying on the tin trade, which materials they sell at extraordinary rates to the labouring tinners, to be paid for the same in tin, much under the market price. And having once got those people into their debt, they do, by interest and extortion, always keep them so poor, that (to gratify the London pewterers and merchants that imploy them, and for another interest) they compel those poor tinners to sell at what price they please, and by that means do govern the market not only to the great detriment of the county, but to the disadvantage of the kingdom.

"Now the tin trade being divided into so many people's hands, as those labouring adventuring tinners are, it will be difficult to do them good, but by a law enacted to redress their grievances, and such a law as (being executed) may have the like effect with that of the *novissima imposta*, when the Venetians had almost lost the Western trade. And we, having so far lost our Western trade of tin, that the labouring tinners can scarce get their bread, I am of opinion that we may regain it with advantage, and raise the price of tin in some degree, if (after the precedent and example of the Venetians) a *novissima imposta* be laid upon all such as shall buy and sell tin in the counties of Cornwall and Devon, under three or four pounds a hundred, or such a price as the King's Most Excellent Majesty, the Right Honourable the Lords Spiritual and Temporal, and the Honourable the Commons in Parliament, shall think meet. And tin being now at 50s. per cent., such an

imposition will be of considerable advantage to the nation, both in general, and in particular. At four £ per cent. (considering the present price) the King will gain by the benefit and advantage of his subjects, altho' his Majesty should have no more than his former duty. The kingdom will gain (according to the present rate of tin) three parts in eight of all that is transported, because the same quantity, being transported at that price, will occasion the importation of three-eighth parts more in return, either in money or merchandise; for all other markets are governed by the first market price.

"The county in general will gain by it, because land and trade are in natural sympathy; and the tinners, having £4 a hundred for their tin, will have the more money and credit to support themselves and their families.

"The Cornish factors will gain by it three-eighth parts in their provision, if no more, and this will take away the occasion of grinding the poor to satisfie the principals, &c.

"The London pewterers will have the like advantage, insomuch as they are factors for Tin. And I have heard the chiefest of them wish that the price of tin might never be less than £3 a hundred in Cornwall.

"And, after all, the principal merchants can be no losers by it, if it be true what a certain merchant once wrote me at Zant, "That the dearer they bought abroad, the dearer they sold at home." So that it is as much the interest of the whole kingdom to keep up the price of tin in Cornwall, as it was for the Venetians, the Zanteots, and the Praemorratory, to keep up the price of currants at Zant.

"And that it may not be urged that the advancing the price of tin will cause the less quantity thereof to be transported, I must here take notice, that there is no part of the known world, besides Cornwall and Devon, that doth produce tin, unless it be Germany and the East Indies; and the tin which is made there is not so good as our tin by 20s. the hundred; nor can they afford to sell the same so cheap as £5 per cent.

"Neither will the East India or German tin serve so well as ours, for the very many uses which are made thereof throughout the world; and, not to mention its excellent usefulness for making looking-glasses, lackering, painting, &c., I am informed that the finest earthenware in the world cannot be made without our Cornish tin, which occasions so great a consumption of that commodity, beyond what is expended in all common uses. And further, it hath been observed, that when the greatest quantities of tin have been made in Cornwall, that there hath been none left uncoined or unsold; and the higher the price, the better those qualities have gone off; which (to me) seems a good argument of a necessity the world is under to buy this commodity of us. And their necessity, as well as our great costs and charges, and the danger and difficulty of coming at the tin, should bring us to understand its true value, and make our utmost advantage by it; and did we make but half the quantity of tin we now do, we might advance that quantity to what price we pleased; and then the one-half of the charges would be saved also.

"The charge of deals, cordage, and iron, which for the most part come from Norway, the East Country, and Spain, and eat up a great part of the profit, would then be but half as much.

"And one half of the labourers would be imployed in the fishing trade, &c., and to improve the lands by husbandry, that county being capable of improvement that way, to double the value it is now off, besides the advantage that might be made by a full improvement of the fishery, &c.

"And now to show the deplorable circumstance of the poor labouring tinners, we will suppose (for demonstration sake) there are eight thousand tinners partly imployed about the tinning trade, although I am satisfied that they much exceed that number, who (with their families) depend upon the product of their labour.

"And all the tin coined in Cornwall in the year 1692 (which was the year before I designed to publish these grievances) was, by the coinage-books of that county, 11,174 pieces, and the coinage duty thereof being 4s. a hundred in Cornwall, amounted that year to £5,449 17s. By which it doth appear that there must have been 27,249 cwt. of tin made that year in Cornwall only.

"And supposing that quantity sold at 50s. per cent., the whole product of the tin, made in Cornwall in the year 1692, must then come to £69,222 10s., which is a sum much inferior to the £200,000 a year and upwards.

"Now out of this £69,222 10s. must be paid (clear of all charges), to the bounder and lord of the soil, for toll and farm, about a fifth part of the whole, which comes to £18,844 8s.*

"Which, being deducted out of the above said £69,222 10s., there will remain clear to be divided among the said eight thousand tinners, but £40,338 0s. 2d., which comes to £5 10d. and about a half-farthing to each tinner.

"And this is all each tinner hath to maintain himself and family, and for his whole year's hard labour, not only underground, but under God knows how many grievances.

"But indeed they have been the better able to bear them, as being the most Herculean and stoutest men upon earth, and, for their most faithful and loyal services, have the greatest privileges of liberty and property of any people in the kingdom.

"For there are other grievances relating to the tin trade, which are, almost if not altogether, as prejudicial as what hath been said.

"The Cornish factors, and others, are not the only causes of the poor tinners' misery: the Cornish lawyers must come in for a share too. For as the factors grind the poor tinners to gratify the principal traders, and thereby increase their commissions, &c., so the lawyer (upon the discovery of a rich mine) (taking the advantage of the tinners' ignorance in the stannary laws, they being not set forth and published in print) do use all means (by way of pretended justice) to right those clients against the bounder, the landlord, or their fellow-adventurers, when in truth it is in the main a contrivance to

	£	s.	d.
* The charges of *smiths' work*, *timber*, *ropes*, and *candles*, we compute to each man in a year about £1, which for eight thousand men is	8,000	0	0
And supposing the *dressing* and stamping to make every hundred of tin comes to 2s. 6d., it amounts, for the whole year's tin, to	3,206	2	6
The charges of *refining* that year's tin at £1 10s. the *tide*, computing one thousand of tin, to be refined in each tide, comes to	2,725	7	0
The charges of *carrying*, and the expenses at the refining or blowing-house, at 10s. the tide, comes to	908	12	4
The whole sum to be deducted comes to	£14,840	1	10

make themselves masters of those mines, and the profits thereof, and the tinners the slaves only to dig the oar for them.

"And this they the sooner do, because their fees are so great, and the law suits (which they create) so dilatory that (in proportion) they exceed all other grievances, whereas the tinner's privilege (as I am informed) is to have their proceedings at law altogether in English; and, upon payment of a penny only, they are at liberty to appear in person, and to speak and act for themselves, that their causes may be the sooner ended.

"Upon the whole, it may be said that it is with the tinner and his tin, as it is with the Spaniard and his silver; and indeed the tinner takes all the pain, and others carry away the profit."

Thus ends the best information we possess of the grievances of the Cornish tinners at a time when tin mining had reached its lowest condition.

Mr. Scawen, of Millin-ike,* Vice-Warden of the Stannaries in the time of Charles II., complains that the revenues from tin were very small. They remained so until the eighteenth century, the block tin, produced annually up to 1713, being never more than 1,600 tons.

In 1730 the tin-plate manufacture was established, and this gave an impetus to the tin trade. The manufacture of tin plate is so directly connected with the progress of tin mining, that a few lines must be devoted to its history.

The manufacture of tin plate existed in Bohemia in 1620, and had been known in that country for many years. The process of tinning iron had been kept very secret. Nearly all the tin-plate works were in the hands of the reigning duke, and consequently the methods were carefully guarded. The secret was said to have been brought to England in 1670, but Réaumur, writing in 1725, says: "It is said that it (tin plating) was kept a secret there (in Bohemia) very carefully; but where is the country, and which is the trade, where workmen are not mysterious!" An Englishman is said to have visited Saxony in 1605, and to have found many flourishing manufactures there. It was, however, about the year 1625 that eleven English gentlemen found the money which enabled Mr. Andrew Yarranton to visit Saxony, for the purpose of acquiring some exact knowledge of the manufacture. He is said to have been accompanied by an able fireman who understood the nature of iron. With an interpreter they visited Dresden, and were well received. Yarranton certainly gained much knowledge of the manufacture, for, returning to England, he made many parcels of tin plate, which were sent to London and to Worcester, "And all workmen that wrought upon them, agreeing that the plates, and the metal they were made of, was much better than those plates which were made in Germany, and would work more pliable, and serve for many more profitable uses than the German plates would do. Upon which preparations were made to set this beneficial thing at work for the improvement of our own minerals and setting the poor at work." † The first attempt to manufacture tin plates was made at the village of Pontypool, in Monmouth, by Major John Hanbury, in 1720.‡

* Signifying Mill-Lake, in the parish of St. Germans.
† See "England's Improvement by Land and Sea." By Andrew Yarranton. 1698.
‡ "A History of the Trade in Tin," &c. By Phillip William Flower. 1880.

This new manufacture considerably improved the condition of the tin mines of the west; but war being declared in 1744, the means of transporting tin by sea to London was stopped. About this time a "committee of gentlemen" was formed to consider a proposal made by the Society of Mines Royal, to farm the tin for seven years.

From this report we learn that the prices per cwt. for grain tin was £3 9s., and for block tin £3 5s. Sir John St. Aubyn, who was very active, obtained from the Admiralty a convoy for the tin ships, and he warned the tinners not to sell in Cornwall at £50 per ton, since Cleeve, a London merchant, would give £60. In 1746 this price was still maintained, and the quantity raised per annum was still increasing. In 1748, Mr. William Lemon informs us that 2,329 tons of block tin had been produced, the price being £64, while nine years later the quantity had increased to 2,595 tons, but the price had fallen to £59. From this date to 1758 the estimated value was £180,000.*

Notwithstanding what has been already said in respect to the progress of the tin trade, and of the various matters incidental thereto, it appears desirable that some description should be given of the mode adopted by the miners of the last century in obtaining, and in smelting their tin, and a statement made of their views respecting the origin of that metallic treasure.

Carew, in the "Survey of Cornwall," 1769, thus describes the ideas prevalent with the Cornish miners, as to the mode of the occurrence of tin, and the methods of search adopted by them: "The Cornish Tynners hold a strong imagination that in the withdrawing of Noah's flood to the sea, the same took his course from east to west, violently breaking up, and forcibly carrying with it the earth, trees, and rocks, anything which lay loosely near the upper face of the ground. To confirm the likelihood of which supposed truth, they do many times digge up whole and huge timber trees, which they conceive at the Deluge to have been overturned and whelmed, but, whether then or sithence, probable is, that some such cause produced the effect. Hence it cometh, that albeit the tynne lay couched at first in certaine strakes amongst the rockes, like a tree or the veins in a man's body,

* MS. letters to Dr. Borlase, and from Mr. W. Lemon, quoted by Mr. W. C. Borlase in his "Historical Sketch of the Tin Trade."

NOTE ON THE PRODUCTION OF TIN.

	Mr. Scawen, of Millin-ike, was Vice-Warden of the Stannaries.	
James I. and Charles I.	The amount of Block Tin yearly was from	1,400 to 1,600 tons.
Queen Anne and George I.	One year with another amounted to something more than .	1,600 „
In 1742.	A proposal was made by the Mines Royal Company in London to raise £140,000 to encourage the tin trade by farming that commodity for seven years at a certain price. A committee of Cornish gentlemen were appointed to consider the proposals. They reported "That the quantity of tin raised yearly in Cornwall, at an average for many years last past, hath been about	2,100 „
	"And resolved that £3 9s. for grain tin, and £3 5s. per hundred weight for common tin, are the lowest prices for which such tin will be sold to the contractors, exclusive of all coinage, duties, and fees."	
In 1778.	Pryce says, "We have coined in one year . . .	3,600 „
	For the last twenty years, the annual average has been about	3,000 „

from the depth whereof the maine load spreadeth out his branches until they approach the open ayre, yet they have now two kinds of tynne workes, *stream* and *load*; for (they say) the foremencioned flood carried together with the moved rocks and earth so much of the load as was inclosed therein, and at the asswaging left the same scattered here and there in valleys and ryvers where it passed, which being sought and digged is called *stream worke*; under this title they comprise also the Moore works, growing from the like occasion." They maintain these works to have been verie ancient, and first wrought by the *Jewes* with Pickaxes of Holme, Boxe, and Hartshorne. They proove this by the name of those places yet enduring, to wit, *Attall Sarazin*, in English the *Jewes' Offcast*,* and by those tools daily found amongst the rubble of such works. And it may well be that, as Akornes made good bread before Ceres taught the use of corne, and sharp stones served the Indians for knives before they obtained them in iron, so in the infancie of knowledge these poor instruments, for want of better, did supplie a town." †

The following passage, from a much more recent author, shows that similar ideas prevailed in his time (1811) as were common in the time of Carew: "The peculiar situation," observed Mr. Joseph Carne, "in which nearly all the stream tin of Cornwall is found, compared with the localities of the most productive tin veins, is highly illustrative of the direction in which the current of the Deluge swept over the surface. All the productive streams are in the valleys which open to the sea on the eastern side of the Cornish peninsula, whilst most of the richest veins are situated near the northern coast, where all the valleys open towards the north. Most of these valleys have been explored, but although small portions of tin have been found in many of them, no extensive beds have ever been discovered. The mines, for instance, of the parishes of Lelant, Gwinear, Camborne, Illogan, St.

* "As for the name of the castaways, *Attal Sarazin*, it does not signify the Jews' offcast, but the leaving of the Saracens, as Mr. Camden truly observes in his 'Britannica,' and from thence infers that the Saxons (who had never, that I can find, any firm footing in the country) seem not to have meddled with them; or at most to have only employed the Saracens (if they did mean, saith Holland's interpolation, by that means the ancient *Panyms*), so that this seems to have been the more modern name, which is now quite disused; and these old works are now called by their more ancient name, Wheal an Jethewon, or Works of the Jews; whose aqueducts, levels, &c., are to be seen all over those parts of the country where tin is found, as particularly in St. Piran in the Sands, St. Agnes, &c. So that it is very probable, as Mr. Carew says, that these Jewish workmen were brought over here by the Flavian family, after the destruction of Jerusalem, and their general dispersion."—*Carew's "Survey of Cornwall." De Dunstanville's edition* (1811).

† In Carew's "Survey of Cornwall," to which are added notes, illustrative of its history and antiquities, by the late Thomas Jenkins, Esq., and now first published by Francis, Lord de Dunstanville, 1811, we find the following:—

"The opinion of Noah's flood taking, as it withdrew, its course from east to west, has no other foundation than from all or most of the tin veins or loads running from east to west throughout the country; for which some would give a philosophical reason."

"It is likewise almost certain, that tin was first sought for in the stream works, as the prodigious working throughout the country of that kind, and the nature of the thing, do pleasingly show. And on the failure of the streams, they were forced to have recourse to the *load* or *meine* (*i.e.* the rock or stone) as they call it.

"Besides these ancient stream works, which are now very much worn out, we have another sort of them, occasioned by the refuse and leaving of the stamping-mills, &c., which are carried by the streams down to the lower grounds, and after many years lying, necessary to consume the mixture of bad metal and poder (as they call it), viz. mundick, copper, &c., yield very good profit to the adventurers, whom they call by a particular name *sappiers*. . . . Of late years, those lowlands and sands under St. Piran, Arwothal, covered almost every tide with the sea, have, on its going off, employed some hundreds of poor men, women, and little children, incapable of otherwise earning their bread, and turned to very good account to the neighbouring inhabitants. The lowlands also under St. Blazey and Tywardeath."

Agnes, and Perranzabula, are all near the northern coast, but there are no productive streams in any of those parishes. On the southern side, however, are the streams of Perran-Arworthat, Ladock, St. Stephens, Roche, St. Austell, Luxillian, &c. Now, on looking at the direction which the streams bear from the mines, it will appear most probable that the course of the current which swept the tin from its original situation must have been from north to south, or rather from N.N.W. to S.S.E." *

To return to Carew, he continues: "There are also taken up in such works certaine little tooles, heads of brasse, which some terme thunder axes (*celts*), but they make small show of any profitable use. Neither were the Romans ignorant of this trade, as may appear by a brass coyne of Domitian's found in one of these works, and fallen into my hands; and perhaps under one of those *Flavians*, the Jewish workmen made here their first arrivance. They discover these workes by certain tynne stones lying on the face of the ground, which they term *shoad*, as shed from the main load and made somewhat smooth and round by the water's wash and wearing. Where the fynding of these affordeth a tempting likelihood, the tynners go to work casting up trenches before them, in depth 5 or 6 foote, more or lesse, as the loose ground went, and 3 or 4 in breadth, gathering up such *shoad* as this turning of the earth doth offer to their sight. If any ryver thwart them, and that they resolve to search his bed, hee is trained by a new channel from his former course. This yieldeth a speedie and gainful recompense to the adventurers of the search, but I hold it little beneficial to the owners of the soil.

"To find the *load workes*, their first labour is also employed in seeking this *shoad*, which either lieth open on the grasse, or but shallow bye coursed. Having found any such, they conjecture by the sight of the ground which way the flood came which brought it thither, and so give a guess as to the place wherever it was broken off. There they *sincke a shaft* or pit of five or six foot in lengthe, two or three foot in breadth, and seven or eight foot in depth, to prove whether they may so meete with the *load*. By this *shaft* they also discerne which was the quicke ground (as they call it) that mooved with the flood, and which the firm, wherein no *shoad* doth lie. If they miss the *load* in one place they *sincke* a like shaft in another beyond that, commonly farther up towards the hill, and so a third and fourth, until they light at last upon it."

After some irrelevant matter on the question of the "tynne groweth," which Carew does not entirely believe, he continues: "The colour both of the *shoad* and *load* resembleth his bed, as the sea-sand doth the cliffes, and is so diversified to reddish, blackish, duskie, and such other earthly colours. If the *load* wherein the tynne lieth carrieth a foote and a half in breadth and be no overbarriers, it is accompted a verie rich work, but commonly the same exceedeth not a foote, unless many *loades* occurre together. When the new found work intiseth with probabilitie of profit, the discoverer doth commonly associate himself with some more partners, because the charge ammounteth mostly verrie high for any one man's purse, except lined beyond ordinary, to reach unto; and if the worke doe fail, many shoulders

* "Trans. Geol. Society of Cornwall," vol. iv. p. 110.

will more easily support the burthen. These partners consist of either such tinners as worke to their owne behalf, or such adventurers as put in hired labourers. The hirelings stand at a certain wages, either by the day, which may be about eightpence, or for the yeare, being betweene four and six pounds, as their deserving can drive the bargains, at both which rates they must find themselves. If the worke carrie some importance and requires the travaile of many hands, that hath his name, and they their overseer, whome they terme their captaine, such as the *Pel*, *Whilancleuth*, in English, The Worke of the Ditches; *Pulskan*, that is, *The Myrie Head; Cruegbraaz*, The Great Borough; *Sanit Margets*, and many surnamed *Balls*, which betokeneth the vales where the works are set on foote."

The duties of the captain—"setting the taskes," "binding the workes," placing the pumps, &c., are then fully given. "In most cases," continues Carew, "their toyle is so extreeme, as they cannot endure it more than above four hours in a day, but are succeeded by spells; the residue of the time, they weare out at *Coytes*, *Kayles*, or like idle exercises. Their kaylender also alloweth them more holydayes than are warranted by the Church, our lawes, or their own profit."

"Their ordinary tooles are a pickaxe of yron, about sixteen inches long, sharpened at one end to picke, and flat-headed at the other to drive certaine little yron wedges wherewith they cleave the rockes. They have also a brood shovell, the utter part of yron, the middle of timbre, into which the staffe is slopewise fastened. (See Fig. 5, p. 30.)

"Their manner of working in the load mines is to follow the *load* as it lieth, either sidelong or downe-right: both ways the deeper they sink the greater they find the *load*. When they light upon a small veine, or chance to leese the load which they wrought, by means of certaine strings that may hap to cross it, they begin at another place near at hand, and so draw by gesse to the main *load* again. If the *load* lie right downe they follow it sometimes to the depth of fourtie or fiftie fathom. These load works, *Diod. Sic. l.* 5, *cap.* 8, seemeth to point at where, he saith, that the inhabitants of *Velerium Promontine* digge up tin out of rockie ground. From some of their bottoms you shall at noonedayes discrie the starrs;* the workmen are let down and taken up in a stirrup, by two men who would winde. If the *load* lie slopewise, the tynners digge a convenient depth, and then passe forward under ground so far as the ayre will yield them breathing, which, as it begineth to faile, they *sincke* a *shaft* down thither from the top to admit a renewing vent, which, notwithstanding, their work is most by candlelight. In these passages they meete sometimes with verie loose earth, sometimes with exceeding hard rockes, and sometimes with great streams of water. The loose earth is propped by frames of timber work as they go, and yet now and then falling downe, either presseth the poore workmen to death, or stoppeth them from returning. To part the rockes they have the foremencioned axes and wedges, with which mostly they make speedie way, and yet (not seldome) are so tied by the teeth as a good workman shall hardly be able to have three foot in space of so many weeks.

* This proves that the early miners must have worked to a greater depth than it is usually supposed they were capable of doing.

While thus they play the mold warps, unsavorie damps doe here and there distemper their heads.

"(*Addit*).—They cal it the bringing of an addit or audit when they begin to trench without, and carrie the same throw the ground to the tyn worke somewhat deeper than the water doth lie, thereby to give it passage away. This addit they either fetch athwart the whole *load* or right from the branch where they worke, as the next valley ministreth the fittest opportunitie for soonest cutting into the hill; and therefore a gentleman of good knowledge deduceth this name of addit—*Ab aditu ad aquas.* Surely the practice is cunning in device, costly in charge, and long in effecting, and yet, when all is done, many times the load falleth away, and they may sing with *Augustus'* bird, *Opera et impensa perriit.*"

Carew pursues his subject to the "Maner of dressing" and "crazing" and "washing," and on to "melting." "We will now procede," he writes, "to take a view of the orders and customes most generally used by the tynners. Their workes, both *shan* and *load*, lie either in *severall* or in *wastrell*, that is, in enclosed grounds or on commons." These terms were in law as follows:—

"In *severall* no man can search for tin without leave first obtained from the lorde of the soile, who, when any myne is found, may worke it wholly himself, or associate partners, or set it out at a farme certain, or leave it unwrought, at his pleasure.

"In *wastrel* it is lawful for any man to make trial of his fortune that way, provided that he acknowledge the lorde's right by sharing out unto him a certaine part which they call toll: a custome savouring more of indifferencie than the tynners' constitutions in Devon, which inable them to digge for tynne in any man's ground, inclosed or unclosed, without license, tribute, or satisfaction. The wastrel works are reckoned amongst *chattels*, and may pass by worde or will." Of the rules of sharing, Carew says:—

"*Doles*, or shares, they make thereof, and proportionably divide the gains and charges. The lorde of the soyle is most-where allowed libertie to place one workman in everie fifteene for himself, at like hand with the adventurers, if he be so disposed." And of measures he says:—

"They measure their black tynne by the *gill*, the *topliffe*, the *dish*, and the *foote*, which containeth a pint, a pottel, a gallon, and towards two gallons."

The tin miner, having obtained his masses of tin ore, whether large or small, took them to the "stamping mill," by which they were broken, and then to the "crazing mill," where they were reduced to a fine sand. "However," says Carew, "of late times they mostly use wet stampers, and so have no need of crazing mills for their best stuffe, but only for the crust of their tayles." The following passage, giving several examples of the rudeness of the processes adopted in Carew's time, is copied at length:—

"The stream, after it hath forsaken the mill, is made to fall by certain degrees, one somewhat distant from the other, upon each of which, at every discent lyeth a green turfe, three or four feet square and one foot thick. On this the tinner layeth a certain portion of the sandy tinne, and with his shovell softly tosseth the same to and from, that, through this stirring, the water which runneth over it may wash away the light earth from the tinne,

which, of a heavier substance, lyeth faste on the turff. Having so cleaned one portion, he setteth the same aside and begineth with another, until his labour take end with his taske. The best of those turfes (for all sorts serve not) are fetched about two miles to the eastward of St. Michael's Mount, where, at low water, they cast aside the sand and dig them up: they are full of rootes of trees, and on some of them nuts have been found, which confirmeth my former assertion of the sea's intrusion. After it is thus washed, they put the remnant into a wooden dish, broad, flat, and round, being about two foot over, and having two handles fastened at the side, by which they softly shogge the same to and fro in the water between their legges, as they sit over it, until what's over of the earthie substance there was left be flitted away. Some of later time, with a sleighter invention and lighter labour, doe cause certain boys to stir it up and down with their feet, which worketh the same effect; the residue of this often cleaning they call 'black tynne,' which is proportionably divided to everie of the adventurers, when the lord's part hath been first deducted upon the whole.

"Then doth every man carry his portion to the blowing-house, where the same is melted with charcoal fire blown by a great pair of bellows moved with water-wheele, and so cast into pieces of a long and thicke squareness, from three hundred to four hundred pounds weight, at which time the owner's marke is set thereon." Carew then wastes many words of condolence on the tinners, and expresses his wonder that "any gaine could traine men to undertake such pains and perile." He then continues: "During the tinne thus melting in the blowing-house, divers light sparkles thereof are, by the forcible wind which the bellows sendeth forth, driven up to the thatched roof. For which cause the owners doe once in seven or eight years burn those houses, and find so much of this light tin in the ashes as payeth for the new building, with a gaineful overplus. A strange practice (certes), for thrift's sake to set our house on fire. Others do frame the tunnels of the chimnies very large and slope, therein to harbour those sparkles and to save the burning. This casualtie may bee worth the owner some ten pounds by the year or better if his mill have store of sutors. But sithence I gathered sticks to the building of this poor nest, Sir Francis Godolphin (whose kind helpe hath much advanced this my playing labour), entertained a Dutch mineral man, and taking light from his experience, but building thereon farre more profitable conclusions of his own invention, hath practised a more saving way in these matters, and besides made tynne with good profit of that refuse which the tynners rejected as nothing worth."

The following note on the "History of Mining," and especially of the "old men's workings," is of interest: "On the granite bosses of Cornwall, especially at Wendron and St. Just, most of the lodes appear to have been discovered and worked a long time back; the remains of the workings mark the course of the lodes, and the lodes may be traced by these workings on their backs, called the 'old men's workings.' The land appears to have been searched very closely, as almost every tin lode has been thus worked on, done by *cross-teening* (cos-teaning), sinking shallow pits, on the surface, and observing the shoad stones beneath the soil. These lodes are worked to such a depth as the miners could go without machinery, and the tradition at Wendron is

that the water and tin stuff were drawn up by kibbles. There is a little mine about a mile south of Carn Menelez Hill where the old men worked down thirty fathoms, where the water now requires a steam-engine, 40-inch cylinder, with a plunger 7 feet stroke and 11 inches diameter, making five strokes a minute, to keep the water—144 gallons a minute (area 95 inches, equal to 144 gallons a minute). The tradition of the neighbourhood is, that before the introduction of the steam-engine, about 150 kibbles were at work there drawing *water* and tin stuff, and this, from the present amount of water, appears to be about the quantity of labour required. 'The old men' seem to have hunted up the whole country for tin lodes, and worked as far as practicable with their means."—N. WHITLEY.

The period at which the use of gunpowder was introduced into our mines has been a subject of much dispute. Mr. Hawkins thinks that it cannot be traced higher than the beginning of the last century, or a century later than its invention in Germany. Mr. Davis Gilbert, in 1792, states that he believes gunpowder to have been introduced by the Germans in the eastern mining districts of Cornwall. One old man informed Mr. Gilbert that it was first used in the district of Leland, Zennor, and St. Ives, about ninety years previously (*i.e.* 1700), by two men who came from the east, named Bell and Case, and that they affected to keep their operations a secret, suffering no one to see them charge the holes.*

I have been favoured with the following extract from an old register in the parish of Breage, which fixes the period more decidedly.

"Thomas Epsly, senior, of Chilchumpton, parish of Bath and Wells in Somersetshire, he was the man that brought that raree invention of shooting the rocks, which came here in June, 1689, and he died at the ball, and was buried at Breag the 16th day of December, in the yeare of our Lord Christ 1689.

"A correct extract from an old Breage Register. "EDW. W. PRIDMORE,
"Vicar of Breage."

Mr. Thomas Tonkin, who added numerous notes to Carew's "Survey of Cornwall," writing July 9th, 1733, says: "When they meet with rocks and very hard ground, as sometimes they do, with such as require not only three weeks, but three months, to hew so many feet through the same, they formerly burnt furze and faggots, &c., to break the rocks; but that proving insufficient, and very often fatal to the workmen, by the sudden change of wind, which drove down the smoke upon them and suffocated them, *they have of late had recourse to gunpowder*, by boring holes in them, in the nature of mining of towns besieged. But this device has been likewise attended with many sad accidents, by the powder taking fire too soon by a spark struck from the rod in driving; which hath of late been much remedied by a method introduced from abroad by Major Joseph Sawle, as used in the mines in sieges: and that by not using of any rod, but by covering the powder and fuse with fine earth, which answers full as well as if the *stupple* was rammed in."

From this it is evident that gunpowder was but very little used in Tonkin's time, although it is clear that Epsly, a working miner, introduced it to the mines in Cornwall forty-four years before Tonkin wrote.

Mr. Pryce states that he saw a note from Mr. Scawen, as Vice-Warden of the Stannaries, in which he complained, as we have already stated,

* Transactions of the Royal Geological Society of Cornwall."

that the tin revenues were small. This was only a temporary depression, for in the reigns of James I., about 1620, and Charles I., about 1630, the amount of block tin yearly was from 1,400 to 1,600 tons. It was also found by the last two farms in Queen Anne's reign (about 1710), and the beginning of George I.'s (1715), that block tin, one year with another, amounted to something more than 1,600, so that in the space of 110 years its mean proportion was equal to 1,500 tons per annum. Since that time a gradual increase for thirty years followed. In 1742 a proposal was made by the Mines Royal Company in London to raise £140,000 to encourage the tin trade, by farming that commodity for seven years at a certain price. A committee of Cornish gentlemen were appointed to consider the proposals, and they reported "that the quantity of tin raised yearly in Cornwall, at any average for many years last past, hath been about 2,100 tons; and resolved that £3 9s. for grain tin, and £3 5s. per hundred for common tin, are the lowest prices for which such tin should be sold to the contractor, exclusive of all coinage duties and fees."

Pryce says, 1778: "It is a fact that we have coined 3,600 tons of block tin in one year, and for the last twenty years the annual average has been about 3,000 tons, which is double the quantity coined annually but sixty years ago, and one-third increase for the last thirty."

As, with the close of the eighteenth century, the practice of "streaming for tin" was gradually passing away, from the exhaustion of the alluvial deposits, this appears to be the proper place to introduce some examination of the conditions under which this *stream tin* was found.

The accumulation of gravels in the valleys of Cornwall, and in many of the slighter depressions on the widespread moors of the county, and on the side of hills, all show that the powerful action of water in the state of flood has led to this distribution of detrital matter. There cannot be a doubt but that all the stanniferous gravels have been derived from the decomposition of the rocks situated in the higher grounds, and that their present position is due to the influence of torrents. Sir Henry de la Beche says: "If we regard the surface of Cornwall, in which a crust of decomposed or disintegrated rock now exists, one arising from the action of atmospheric influences, and imagine a body of water to rush violently over it, carrying this disintegrated or decomposed surface before it down to the present valleys, stream tin would be found in them, much as it has been hitherto discovered, though not perhaps so abundantly, if we infer from the present mode of occurrence of tin ores so comparatively near the surface in many lodes, that a previous surface, now removed, may have been still richer with respect to this metal than that which we now find." *

It appears in St. Agnes, a district remarkably rich in stanniferous deposits, that the evidences of dislocation, of slides and heaves in the mines of Penhalls and Wheal Kitty, distinctly prove that many hundred feet of matter have been removed from the surface. Indeed, the indications of denudation over all parts of the western peninsula are obvious, from Dartmoor to the Land's End.

* "Report on the Geology of Cornwall, Devon, and West Somerset." By Henry T. de la Beche, F.R.S. 1839.

Those who have studied the decomposed Granite near St. Austell, traversed as it is by a multitude of branches and strings of oxide of tin, would have little difficulty in perceiving that if a body of water were made to rush over it, the decomposed Granite would be readily removed, and that the broken up strings and branches of tin ore would be rolled into pebbles and distributed, just as the stream tin now occurs, down the valleys in the neighbourhood. The specific gravity of stream tin varies, according to its purity, from 5·6 to 6·9.

The specific gravity of Granite is from	. . . . .	2·62 to 2·74
Argillaceous Slate and Grauwacke ,,	. . . . .	2·64 ,, 2·81
Schorl rock ,,	. . . . .	2·86
Quartz ,,	. . . . .	2·63
Felspar ,,	. . . . .	2·53 ,, 2·60
Mica ,,	. . . . .	2·64

The following is an abstract from Pryce: Tin stones must come to rest, from the diminished velocity of the water, long before any of the other materials do so. When, therefore, the transporting water can no longer carry tin stones onwards, it will be capable of pushing forwards, or of retaining in mechanical suspension, the other gravel associated with it, so that a fundamental layer of tin-stone pebbles might be accumulated at the bottom of a valley and remain settled, while lighter bodies were driven or carried forward, or driven over it, due allowance being made for the forms and volumes of the component parts of the whole transported detritus, iron-stone pebbles included.

Streaming, or washing the deposits in the valleys, or hollows, and separating the heavy oxide of tin, black tin, from the pebbles or sand with which it is mixed, is a simple operation. It was, without doubt, at one time the only method by which the Cornish tinner obtained the valuable metal with which he traded with the merchants of Tyre and Sidon. When it was found that the débris to which attention was at first given had been derived from the rocks, naturally the miners began to search the cliffs, where there were any indications of any metal, and hence we find in some districts the rocks have been pierced with numerous holes, the oldest example of mining left to tell us of the operations of the "Old Men." Pryce continues:—

"When a 'Stream Tinner' observed a place favourable in situation, he took a lease, commonly called a *sett*, of the landowner, or lord of the fee, for such a spot of ground, and agreed to pay him a certain part, clear of all expense, in black tin—that is, tin made clean from all waste and ready for smelting. The consideration was generally one sixth, seventh, eighth, or ninth, as was settled between them; or, instead thereof, he contracted to employ so many men and boys annually in his stream works, and to pay the landowner for liberty, from twenty to thirty shillings a year for each man, and so in proportion for every boy; that is, for twelve shillings monthly wages, he articled to pay the lord half as much as for a man.

"He then sank a hatch (shaft), three, five, or seven fathoms deep, to the rocky shelf or clay, on both of which in the same valley the tin was frequently stratified, without any difference in its being more abundant in one than the other. It is found in different places, at various depths, and sometimes stratified, between what is called a first, second, or third shelf. . . . The stratum of stream tin may be from one to ten feet thickness or more; in

breadth from one fathom to almost the width of the valley; and in size from a walnut to the finest sand, the latter making the principal part of the stream, which is intermixed with stones, gravel, and clay, as it was torn from the adjacent hills.

"When he sank down to the tin stratum, he took a shovelful of it and washed off all the waste, and from the tin which was left behind upon the shovel, he judged whether that ground was worth the working or not. If it was 'proving work,' he then got down to the lowest or deepest part of the valley, and dug an open trench, like the tail or *low slovan* of an adit, which was called a level, taking the utmost care to lose no leads in bringing it home to the stream. This level served to drain and carry off all the water and waste from the workings, in proportion as there was a weak or powerful current of water to run through it. Some places might have been very poor, and not worth the expense of working; others again very rich, and thence called *Benheyle* or Living Stream, as was most commonly the case if it were of a *grouan* nature, which, being more lax and sandy, was more easily separated from its native place, or lode, and therefore more abundant and rich in quality according to the known excellence of grouan tin.

"In the latter case the streamer carried off what was called the over-burden, viz. loose earth, rubble, or stone, which covered the stream, so far and so large, as he could manage with conveniency to his employment. If in the progress of his working he was hindered, he *leemed* (or laded) it out with a scoop, or discharged it by a hand pump; but if those simple methods were insufficient, he erected a rag-and-chain pump, so called, or if a rivulet of water were to be rented cheaply at *grass* (*i.e.* at the surface), he erected a water-wheel with balance bobs, and thereby kept his workings clear of superfluous water by discharging it into his level: meanwhile his men dug up the stream tin and washed it at the same time, by casting every shovelful of it, as it rose, into a *tye*, which was an inclined plane of boards for the water to run off, about four feet wide, four high, and nine feet long, in which, with shovels, they turned it over and over again under a cascade of water, that washed through it and separated the waste from the tin, until it became half tin.

"Though there was little dexterity in this manœuvre, yet care was requisite to throw off the *stent*, or rubble, from the tye to itself, whilst another picked out the stones of tin from the *garde*, or *smaller pryany* part of it. During this operation, the best of the tin, by its superior gravity, collected in the head of the tye directly under the cascade, and by degrees became more full of waste as it descended from that place to the end or tail of the tye, which was not worth saving. If there was a copious stream of water near at hand, they cast the refuse into it, by which it was carried so far as to make its exit into the sea. After the tin was thus partly dressed in raising it, they carried it to grass, and when a competent quantity had been collected they proceeded to dress it for *blowing* (*i.e.* for smelting in small black furnaces which are called '*blowing-houses*').

"There are several ways of dressing this kind of tin; but the general method is to make what they call a *Gounce*, which is nothing more than a small tye, and what in mining parts is called *strêke*, in which the

smaller tin is washed over again, as was done before in the tye, but with a less current of water and a larger degree of care and caution, lest the tin be carried off with it. The richer part of the tin lies nearest the head of the gounce, which is carefully taken up, divided, or kept separate, according to its goodness, and put into large vats, or kieves; while the waste that lies in the hinder part of the gounce is dressed over again, till all the tin is taken out, and the remaining waste becomes absolute refuse. The tin is then sifted through wood or wire sieves, whereby the greater particles are divided from the smaller. By this method, likewise, the waste from its levity lies uppermost in the sieve, which is carefully skimmed off and laid aside to work over again. The smallest tin which passes through the wire sieve is put into another finely woven horsehair sieve called a *Dilluer*, by which, and the skill of the workman, it is made merchantable. Some of the nodules, or lumps of tin, are blown or smelted as they come out of the tye, but those which are mixed with waste are put with the refuse of the garde and poor tin, which were in the tails of the tye and gounce, and being sent to the stamping-mill are triturated and pulverised, so that all waste may be cleared from the tin by sundry ablutions, the same as are performed in the dressing of mine tin.

"Stream tin, being prepared and made ready for blowing with a charcoal fire, is carried to the blast furnace, or 'blowing-house;' where formerly the tinner might have his tin blown, paying the owner of the house 20s. for every tide, or twelve hours, for which the blower was obliged to deliver to the tinner, at the ensuing coinage, one hundred gross weight of white tin (metallic tin) for every three feet, or 180 lbs. of stream tin so blown, which is equal to fourteen pounds of metal for twenty of mineral, clear of all expense.

"Now that the blowing-houses are farmed, the tin is usually blown and sold by sample, as the mine tin is at the reverberating furnaces. The furnace itself for blowing the tin is called 'the castle,' on account of its strength, being of massive stones cramped together, with iron, to ensure the united force of fire and air. This fire is made with charcoal excited by two large bellows, which are worked by a water wheel, the same as the iron forges. They are about 8 feet long, and $2\frac{1}{2}$ wide at the broadest part. The fireplace or castle is about 6 feet perpendicular, 2 feet wide in the top part each way, and about 14 inches in the bottom, all made of moor-stone and clay well cemented and cramped together. The pipe or nose of each bellows is fixed 10 inches high from the bottom of the castle, in a large piece of wrought iron called the Hearth eye. The tin and charcoal are laid in the furnace, *stratum super stratum*, in such quantities as are thought proper, so that from 8 to 12 cwt. of tin, by the consumption of twenty-four sixty-gallon packs of charcoal, may be smelted in a tide, or twelve hours. Those bellows are not only useful for igniting the charcoal, but they throw in a steady and powerful air into the castle, which, at the same time that it smelts the tin, forces it out also through a hole at the bottom, about 4 inches high and $1\frac{1}{2}$ inch wide, into a moor-stone trough $6\frac{1}{2}$ feet high and 1 foot wide, called the 'float,' whence it is laded into lesser troughs or moulds, each of which contains about 3 cwt. of metal called slabs. 'Blocks,'

or 'Pieces of tin,' of a well-known form and size, are sold in every market in Europe, and it is sold also in bars and bundles, which, on account of its superior quality, is known by the name of 'grain tin.' This brought a price formerly of 7s., and is further advanced the last two or three years to 10s. or 12s. per hundred more than mine tin is sold for, because it is smelted from a pure mineral by a charcoal fire; whereas mine tin is usually corrupted with mundic and other minerals, and is smelted with a bituminous fire, which communicates a harsh sulphurous injurious quality to the metal" (*Pryce*, 1778).

Borlase was so careful an observer, that it is important to collate his description of mines and mining in his day. There are several streams of tin in St. Stephen, Branel, St. Ewe, St. Blazy, and other places, but the most considerable stream of tin in Cornwall is that of St. Austell Moor, which is a narrow valley about a furlong wide (in some places somewhat wider), running nearly three miles from the town of St. Austell southward to the sea. On each side, and at the head above St. Austell, are many hills, betwixt which there are little valleys which all discharge their waters, and whatever else they receive from the higher grounds, into St. Austell Moor, whence it happens that the ground of this moor is all adventitious for about three fathoms deep, the "shodes" and streams from the hills on each being here collected and ranged into floors, according to their weight and the successive dates of their coming thither. The uppermost coat consists of thin layers of earth, clay, and pebbly gravel, about 5 feet deep. The next stratum is about 6 feet deep, more stony, the stones pebbly formed, with a gravelly sand intermixed. These two coverings being removed, they find great numbers of tin stones from the bigness of a goose egg, and sometimes larger down to the size of the finest sand. The tin is inserted in a stratum of loose smoothed stones, from a foot diameter downwards to the smallest pebble. From the present surface of the ground down to the solid rock or karn, is eighteen feet as a medium. In the solid rock there is no tin. The stream tin is of the purest kind, and great part of it, without any other management than being washed upon the spot, brings thirteen parts from twenty at the melting-house.*

Streams of tin are thus described by Dr. Borlase: "These streams are of different breadths, seldom less than a fathom, oftentimes scattered, though in different quantities, over the whole width of the moor, bottom, or valley, in which they are found; and when several such streams meet they oftentimes make a very rich floor of tin, one stream proving as it were a magnet to the metal of the other."

In the tenement of Douran, in the parish of St. Just (Penrith), in the year 1738, there was a very singular stream of tin discovered. The ore was pulverised, betwixt one foot and one foot and a half in depth or thickness, of various breadth. In the moory ground, where it was first discovered, it had a back of soil or gravel over it only two feet high; but, as the stream advanced farther east, it had still a higher covering, till at last it had all Douran Hill (which may be about forty feet perpendicular) over it, the

* Upon delivering twenty pounds of this tinstone at the smelting-house, the smelter will contract to deliver to the owner's order thirteen pounds of melted tin at the coinage.

stream still continuing its horizontal position. Dr. Borlase, led by the prevailing opinion of his day, refers this to the action of the waters of the deluge, but he does this very doubtfully, and asks: "But whether this remarkable position of arenaceous tin is owing to the waters of the flood (which indeed is a most fertile solution of subterraneous difficulties, but I fear too often recurred to), may be well questioned." He then gives an explanation of his own endeavours to free his mind of the trammels of tradition, but it is very unsatisfactory, since it is purely hypothetical, and unsupported by any natural evidences. However, he gives a very satisfactory description of another remarkable tin stream, which was working in his days (1758).

The "*broil*," or top of the lode, is particularly noticed by Dr. Borlase in his "Natural History of Cornwall." "The lode has its top covered over with a parcel of loose stones and earth, usually of the same impregnate, though in a less degree, of the same colour and cement as the lode, and this in Cornwall we call the 'broil' of the lode.

"This broil not being confined betwixt rocks, as the lode is, is frequently found to have been disturbed, and sometimes wholly dissipated, especially when the walls of the fissure reach up to-day, as they do in naked karns (cairns), but where there is a layer of rubble, or stiff deep clay above the fissure, which is much oftener the case, then the broil is always found covering the lode and brooding as it were over the treasures beneath.

"The broil is found in greater quantity in the valleys than in the tops or sides of hills; on the level ground it is but just moved from its first station, and spread on each side of the vein in an equable manner; but, if the lode has any declivity near it, then many of the loose stones of the broil are found strewn down the hill. In Cornwall we call these dispersed parts of the broil 'shodes.'" *

Tonkin states, in a note to Carew's "Survey of Cornwall," that as late as 1733 the shafts were very unimportant. "As for the damps, they often cure them by sinking a new shaft, which they call an air shaft, and where that cannot be conveniently done by bellows and pipes of lead or leather, a method taken from Dr. Brown's 'Travels and Observations on the Mines in Hungary,' p. 107. This was put in practice the first time by my father, to carry on St. George Adit in Goonlaze, St. Agnes, where by reason *of the great depth (at least forty fathoms from the grass) it was impossible to sink a shaft;* and so to have succeeded without this invention; since which it has been tried in other places with like good success. But note that this was invented by the Lord St. Albans, and practised in Wales by his servant Thomas Bushell, Esqr." †

Lord De Dunstanville adds a note to this. "From the search which has been made during so many centuries for stream tin in Cornwall and Devon, it is difficult to obtain sections of unmoved ground at present, except in situations where the tin-stone pebbles are not very abundant. Hence we can form a very inadequate idea of the great accumulations which must have been first worked, and consequently of the tin-stone pebbles swept into the bottom

* Perhaps from the Teutonic word *Shutten*, to pour forth.
† Fuller's "Worthies in Wales," p. 4.

of valleys, or into basin-shaped depressions (such as occur at the Tregoss Moors, and on the north of Wendron), by the body of water which appears to have passed over this land. Traces of stream works are to be seen from Dartmoor to the Land's End, often in depressions on the higher grounds, as, for example, on the former elevated region, whence tin pebbles have long ceased to be obtained, being the works of the *old men*, as the ancient miners are universally termed in Devon and Cornwall.

"Though the richest deposits seem to have been well worked, and the ground turned over twice or thrice, the tin-stones rejected at one time becoming valuable from their comparative scarcity at another, there is still enough of unmoved ground here and there working to enable us to judge of the accuracy of the general geological facts stated to be observable in connection with the tin-grounds. This is more particularly the case where modern enterprise has directed works beneath the level of the sea, as at Pentuan: or, abstracted the tin-stone pebbles from beneath the silt and sands of an estuary, permitting the latter gradually to fill up the space once occupied by the tin-ground, as is now done in Restronget Creek, near Falmouth, which will be referred to in the section devoted to detrital tin deposits, when a section of the Happy-Union stream work at Pentuan, as observed in 1829 by Mr. Colenso, will be especially noticed.

"From information collected respecting the cutting of the Par Canal, and from mining operations, it would appear that the tin ground in the neighbouring valley of Par was covered by marine deposits to a level that would correspond with that observed in the St. Austell Valley; and it is worthy of note that when the cutting of Par Canal was effected at Pons Mill, near St. Blazey, granite blocks were found arranged for a stone bridge nearly 20 feet beneath the gravel, which had accumulated upon it in no small quantity, probably from the washings of the tin stream works higher up the valley, sections of which have been published by Mr. William Jory Henwood.* The following is a section obtained by Mr. M'Lauchlan from Captain Barrett, of East Crinnis mine. One seen in a shaft sunk in a part of the lower ground near the Par estuary:—

	Feet.	Inches.
1. River deposit	1	6
2. Confused mass of mud, sand, clay, and stones, which has been disturbed by the "stream tinners"	7	0
3. Mud, clay, and vegetable matter, apparently an old surface	8	0
4. Fine sand, containing sea-shells, like cockles, and on the top rolled pebbles.	4	0
5. Mud, clay, sand, wood, nuts, and other vegetable productions mixed	3	0
6. Tin ground, resting upon an uneven surface of slabs	6 inches to 6 feet †	

In the Carnon valley, on the north of Falmouth, and up the continuation of that valley inland, in the direction of the Gwennap mines, we have another example of tin ground partly beneath marine accumulations, and partly covered by common river detritus.

The following is a section of another of the Carnon stream works, by Mr. W. J. Henwood, than whom no man had a more perfect acquaintance with the diverse operations of mining and streaming in Cornwall:—

* "Transactions of the Geological Society of Cornwall," vol. iv. pp. 60-64.
† Sir Henry de la Beche's "Report on the Geology of Devon and Cornwall."

	Feet.	Inches.
1. Sand and mud (*River wash*)	3	0
2. Silt and shells (*Three successive beds*)	0	10
3. Sand and shells (A stream of fresh water percolates this bed)	2	0
4. Silt (*Three beds*)		
5. Sand and shells		
6. Silt, mixed with shells in large quantities		
7. Silt, in some places containing stones		
8. Wood, moss, leaves, nuts, &c., all of a dark colour, resembling what has been charred; a few oyster-shells, animal remains, those of the deer being most abundant, and *some human skulls*	1	6
Towards the sea the bed 8 entirely disappears, giving place to 7, which reposes on		
9. The *tin ground*, which consists of rounded masses of tin ore, in some cases unmixed with any other substances; in others, in a matrix of quartz and schorl, with rounded pieces of slate, granite, and quartz, varying in thickness from a few inches to	12	0*

The *shelf*, or surface of rock, upon which the whole reposes, is composed of the ordinary Clay-Slate (killas) of Cornwall.

The higher stream works at Carnon have been for some years abandoned, the search for stream tin being confined to the bottom of Restronget Creek. At this point works have recently been carried on by Messrs. Taylor, by sinking a cylinder through the tidal waters of the estuary, and working underneath the creek upon the tin ground.

Sir Henry de la Beche says, after remarking that the stream tin found in the north of Cornwall, as well as on the south, was covered by marine deposits to a certain height up the valley, continues, "Here also (Carnon Stream) on the south, a bed in which vegetable remains are abundant, chiefly oak trees (?), the roots of which were described to us as standing in the position in which they appear to have grown, rests on the tin ground towards the seaward termination of the valley." †

Mr. Edward Smith gave, in 1837, the following section of Carnon Stream. This name has been given to a long line of works, so that the minor details may be expected to vary during the distance :—

1. Mud and gravel	7 feet.
2. Granite gravel, intermingled with small pieces resembling charcoal, and a few shells	4 ,,
3. Fine gravel, mud, and shells	12 ,,
About this depth are several irregular strata of oysters, about 4 or 5 feet in thickness, extending irregularly, and within 4 or 5 feet of the tin ground.	
4. Closer mud, intermingled with shells	19 ,,
In this stratum have been found several branches and trunks of trees, some of which had evident marks of having been cut with an axe or other sharp instrument; horns and bones of stags, likewise human skulls.	
5. Tin ground, varying from	1 foot to 6 ,,

Shodes, as defined by Dr. Borlase, requires attention: "Tin is also disseminated on the sides of hills in single stones, sometimes a furlong or more distant from these lodes, and sometimes these loose stones are found together in great numbers, making one continued course from 1 to 10 feet deep, which we call a *stream*, and when there is a good quantity of it the tinners call it, in the Cornish tongue, *Beuheyle*, or a *Living Stream*; that is, a course of stones impregnated with tin. In like manner, when the stone has a small appearance of tin, they say it is *just alive*; when no metal, it is said to be *dead*, and the rubble which contains no metal is called *deads*."

* "Transactions of the Geological Society of Cornwall," vol. iv. p. 58.
† "Geological Survey of Cornwall and Devon," 1839.

In the reign of Queen Anne the tin mines of Cornwall were in a most depressed condition, and several attempts were made to induce the Government to give some assistance to the tin miners. This led eventually to a Convocation, or "*A Parliament of Tinners*," from which the miners of Cornwall were led to expect great benefits. The following condensed statement of this extraordinary meeting will therefore form an interesting supplement to the Historical Sketch of the History of our Earliest Mining Operations.

A Journal of the Convocation of four and twenty Stannators, or Parliament of Tinners for the Stannaries of Cornwall, held at Truro the 20th day of February, in the eighth year of the reign of our Sovereign Lady Queen Anne, before the Hon. Hugh Boscawen, Esq., Lord Warden of the Stannaries of Cornwall and Devon, &c. &c., and by several prerogatives continued and put over unto the 20th day of April, in the ninth year of Her Majesty's reign, A.D. 1710.

The Lord Treasurer Godolphin sent down his nephew, the Lord Warden, with a commission from the Queen to call a Convocation, and with articles and instructions for the said new farm. Mr. Tonkin represents that the "generality of the people, who seldom trouble their heads with what may come after, were very fond of 'the new farm.' But it was not so with most of the gentlemen and principal owners of tin mines." They are said to have been "very indifferent as to a farm, as being truly sensible of those mischiefs that might attend it, and were therefore for taking their chance; or if there must be a farm, were resolved not to accept of it but on the same terms with the former, and a redress of the great grievances occasioned by the surplus tin beyond what was contracted for."

The Convocators returned, "as they were known to be, in the true interest of their country," were divided into two parties—the one of fourteen, distinguished by the title of *Anti-Wardenists*, or the country party; the other called *Wardenists*, or the court party.

In these debates it was soon discovered that the neutral gentlemen had acceded to the Wardenists, and therefore the Anti-Wardenists resolved to avoid the consideration of the Lord Warden's speech, &c., till those two members were returned. To which an unforeseen accident gave them a fair handle likewise, for this very evening some hot-headed fellows, pretending a great deal for the country's welfare, and finding that the majority of the Convocation, &c. &c., were against a farm on the terms proposed, sent to all the tinners in the neighbourhood to force the Convocation to a farm.

Die Sabbati, vicesimo secundo die Aprilis. By sun-rising this morning *the tinners*, and all the mob round the country, to the number of at least 5,000 or 6,000, were come to town according to their summons, and behaved themselves in a very disorderly manner. The result, however, of this tumultuous gathering was that the Lord Warden came forthwith to the Convocation, and having ordered the door of the Coinage Hall to be thrown open, which was immediately filled with a crowd of people, he rose up and made a short speech to this purpose—that the Convocators had the real interest of their country truly at heart, and that they would, he had no doubt, pursue the best methods to obtain it, and that, for his part, they would not show their regard to him in a better manner than by departing immediately to

their respective homes. Upon which the crowd gave a loud huzza, and gradually dispersed.

After several days of very angry and often wordy discussion, it was resolved, "That this Convocation is willing to contract with Her Majesty for the tin of Cornwall for seven years, from the first day of June next, according to the articles of instruction annexed to the Lord Warden's commission for holding this Convocation."

It was ordered that the title of the deed drawn up should be—"That the title thereof be 'An Act of Convocation, or Parliament of Tinners, for a contract with the Hon. Lord Warden, on behalf of Her Majesty, for the tin of Cornwall for seven years, to commence the first day of June, 1710.'" The Convocation attended by arrangement in the Coinage Hall, to meet the Lord Warden, and gave assent and confirmation to the Act for a contract with Her Majesty for the tin of Cornwall.

Mr. Tonkin quaintly says, "Thus under this Convocation, which *met* with great expectations, of what they would do for keeping up the price of tin, and restoring and confirming the laws, customs, and constitutions of the Stannaries, *but performed nothing at all.*" *

Many of the mines of Cornwall have been worked under conditions of exceeding difficulty; but no case of mining enterprise shows so completely the perseverance of the Cornish miner, and his disregard of difficulties, as that of his sinking a shaft in the middle of the sea, and working for some time a tin mine of much promise, called *The Wherry*, near Penzance, midway between Newlyn and Penzance.

This most singular mining work was executed more than a century ago, near the shore. At low water, in a place where a gravelly bottom was left bare, there was discovered a multitude of small veins of tin ore, which crossed each other in every direction and ran through the Elvan rocks. This ridge of rock jutting into the Mount's Bay also contained this mineral in considerable quantities. On several occasions tin miners had worked upon these small veins at low water, especially at spring tides; but the black tin thus discovered rarely paid for the time and labour expended.

* The Prices of Tin per cwt. from 1783 to the end of the century, is from the Report of the Select Committee of the House of Lords on the State of the British Wool Trade:—

	£	s.			£	s.	d.	
1783	4	1	per cwt.	792	4	18	0	per cwt
1784	4	1		793	5	0	6	,,
1785	4	3		794	5	0	3	,,
1786	4	3		795	4	18	4	,,
1787	4	3		796	5	0	3	,,
1788	4	1		797	5	0	6	,,
1789	3	10		798	5	0	5	,,
1790	3	15		799	5	0	5	,,
1791	4	0						

The following quantities of Tin were supplied by the Miners of Cornwall, under the Stocking System, to the East India Company:—

			tons	cwts.	qrs.	lbs.
From October, 1793	to	April, 1794	1232	16	2	17
December, 1794		May, 1795	1202	5	0	26
January, 1796		June, 1796	1202	4	1	14
December, 1796		April, 1797	1062	4	0	9
November, 1797		March, 1798	1229	16	1	15
December, 1798		May, 1799	802	17	1	24
November, 1799		April, 1800	687	10	3	7

* **The annual produce of the Tin Mines of Cornwall, from 1750 to the present time, will be found in the Appendix.**

The first attempts to work this singular mine are said to have been made towards the beginning of the last century, when the small veins of tin were first observed to cross the rocky shoal which is exposed to view at low water. How long this first party of miners persevered in their difficult enterprise, and what were the mechanical aids of which they availed themselves, is not known; but the works, after being sunk to the depth of a very few fathoms in the rock, were abandoned.

About the year 1778 a poor miner in the parish of Breage, whose name was Thomas Curtis, had the boldness to renew the attempt. The distance of the shoal from the neighbouring beach at high water is about 120 fathoms; and this, in consequence of the shallowness of the beach, is not materially lessened at low water. It is calculated that the surface of the rock is covered about ten months in the year, and that the depth of water on it at spring tides is 19 feet. The prevailing winds occasion a very great surf here even in summer, but in winter the sea bursts over the rock in such a manner as to render all attempts to carry on mining operations unavailing.

Such were the difficulties which a poor individual had to surmount whose whole capital, perhaps, was not £10. As the work could be prosecuted only during the short period of time when the rock appeared above water (a period which was still further abridged by the necessity of previously emptying the excavation), three summers were consumed in sinking the pump shaft, a work of mere bodily labour. The use of machinery then became practicable, and a frame of boards being applied to the mouth of the shaft, it was cemented to the rock by pitch and oakum, made water-tight in the same way, and carried up to a sufficient height above the highest spring tide. To support this boarded turret—which was 20 feet high above the rock and 2 feet 1 inch square—against the violence of the surge, eight stout bars of iron were applied in an inclined direction to its sides, four of them below and four of an extraordinary length and thickness above. A platform of boards was then lashed round the top of the turret, supported by four poles, which were firmly connected with these rods. Lastly, upon this platform was fixed a winze for four men.

It was thought that the miners would thus be enabled to pursue their operations at all times, even during the winter months, whenever the weather was not particularly unfavourable; but as soon as the excavation was carried to some extent in a lateral direction, this was found to be impossible; for the sea water penetrated through the fissures of the rock, and in proportion as the workings became enlarged, the labour of raising the waste to the mouth of the shaft increased. Curtis's predecessors, as well as himself, had carried on their excavations too near the surface, which not only made the rock more permeable, but less able to resist the immense pressure of water at high tide, so that it became necessary to support it with large timbers. To add to this disappointment it was found impossible to prevent the water from forcing its way through the shaft during the winter months, or, on account of the swell and surf, to remove the tin-stone from the rock to the beach opposite.

The whole winter, therefore, was a period of inaction; it was not before April that the regular working of the mine could be resumed. Neverthe-

less, the short interval which was still allowed for labour below ground, sufficed most richly to reward the bold and persevering projector, and to give his mine the reputation of a very profitable adventure.

Whether he ever felt a conviction of the possibility of removing so many natural obstacles to his complete success is not known, although there is reason to suppose that he did; for when Mr. Hawkins asks Curtis's "opinion of the scheme of erecting a lighthouse on the tremendous Wolf Rock, he professed his belief in its practicability, but suggested, as far preferable, the blowing up of the entire rock, which he readily engaged to do for a proper remuneration."

The following was the state of The Wherry in the autumn of 1791, as described by Mr. Hawkins in the Geological Society's Transactions:—

"Depth of the pump, shaft, and workings, four fathoms two feet. Breadth of the workings, eighteen feet. The roof was worked away in some places to the thickness of three feet. Twelve men were employed for two hours at the wing in hauling the water, while six men were teaming from the bottoms into the pump. The men worked on the rock for six hours afterwards; in all, eight hours. Thirty sacks of tin-stone were broken on an average every tide; and ten men in the space of six months, working about one-tenth of that time, broke about £600 worth.

"The workings were confined to a course or channel of Elvan, a porphyritic rock, about eighteen feet in breadth, which runs N.W. and S.E., and underlies one foot and a half in a fathom to the S.W. It is discoverable on the beach at half-tide. Besides the small veins of tin which ran through this rock, its whole mass was impregnated with tin to such a degree as to be worth the expense of raising; fifteen feet of the eighteen which composed the breadth of the Elvan producing 1,000 cwt. of 'white tin' in 1,600 sacks, and another foot as much as 1 cwt. of white tin in every sack.

"On a close inspection of the mass in which the tin was thus abundantly dispersed, the grains appear of a crystalline transparency, and so equal in size and regularly distributed as to form, as it were, one of the constituted parts of the porphyry: the term *stannified granite* was applied to it. It is said to have been the first tin-stone that was ever burnt in Cornwall before it was sent to the stamping-mill: a common lime-kiln having been erected for that purpose. The object of this operation was to render the texture of the stone more friable."

In September, 1792, Mr. D. Gilbert wrote to Mr. J. Hawkins as follows: "The course of stanniferous porphyry near Penzance (the Wherry) promises to make a very great mine. There are indications of the tin being continued to a great extent in both directions, and the bottoms are growing longer and remain rich. A house near the green, built with fragments of this stone, which were probably picked up on the shore, or broken from the top of the rock, is, I hear, to be pulled down and rebuilt with other stone, for the sake of its tin. An adventurer told me that £3,000 worth of tin has been raised from this extraordinary mine in the course of the present summer."

In a subsequent letter Mr. Gilbert says: "A steam-engine is erecting on 'the Green' opposite, and they are constructing a wooden bridge from thence to the rock, to serve as a communication, till the engine-shaft has been sunk

sufficiently deep, and a drift worked out to the mine, as a stage for supporting the sliding, or rather hanging rods."

The bridge thus constructed answered also the purpose of conveying the *ore* and *deads* to the shore. In this manner the mine was conducted, and ore to the amount of £70,000 was raised from it. Nor, indeed, were its treasures exhausted at its close, which was as romantic as its commencement. An American vessel broke from its anchorage in Gwavus Lake, and, striking against the stage, demolished the machinery, and thus put an end to an adventure which, both in ingenuity and success, was probably never equalled in any country.*

This mine was again worked a few years since; but although there was a large sum of money expended, and all the advantages of the application of improved machinery secured, it failed to be profitable, and was eventually abandoned. It should be remarked that, in addition to tin, some minerals of a rarer character were produced at the Wherry: amongst others, were valuable ores of Cobalt, and at one period an attempt was made to manufacture Smalts from this ore. This interesting process does not appear to have continued long, and the fact of the manufacture lives only as a tradition. Even within the last few years, good specimens of tin-white cobalt have been collected from the crevices of the rocks, a short distance above low-water level, between Penzance and Newlyn.

The Wherry mine was not the only mine in Cornwall which was worked under the sea. At *Trewavas* mine, not far from *Helstone*, the engine-houses were built on the edge of the most romantic cliffs, and the levels driven out under the waters of the beautiful Mount's Bay, and worked so closely up to the sea bottom, that a large quantity of water penetrated through the rock, and that accumulated in the mine was exceedingly salt. A similar exploration under the sea was made at *Wheal Providence*, near St. Ives. In this mine there were two levels driven at depths below high-water mark of 24 fathoms and 32 fathoms respectively, both of which were wrought 20 fathoms out under the sea. Here the water was not salt, and the miners could scarcely hear the noise of the waves.

A still more remarkable example of mine workings under the sea has been in existence since the days of Pryce (1778).† "At *Wheal Cock*," he says, "they have only a crust between them at most, and though in one place they have barely four feet of stratum to preserve them from the raging sea, yet they have rarely more than a dribble of salt water, which they occasionally stop out with oakum and clay, inserted into the crannies through which it issues." This mine forms a part of *Botallack*, which has been worked at a depth of 1,500 feet below the sea-level, and 2,248 feet under the Atlantic Ocean. Mr. W. J. Henwood relates that, when standing in that part of the mine where but 9 feet of rock stood between him and the ocean, the heavy roll of the large boulders, the ceaseless grinding of the pebbles, the fierce thundering of the billows, with the crackling and boiling as they rebounded, placed a tempest in its most appalling form too vividly before him to be ever forgotten.

* "A Treatise on the Progressive Improvements and Present State of the Manufactures in Metal," vol. iii. Revised by Robert Hunt. 1853.

† "Mineralogia Cornubiensis."

About the end of the last century the tin trade was in a most depressed state, and the following letter, written in 1780 by one of the most active of the tin smelters, is deserving attention:—

Some thoughts on the present mode of carrying on the Tin Trade, so far as it relates to the sending Tin to London and Bristol for sale; with a sketch of a plan for putting that trade on an eligible footing. An Address to the Gentlemen Tinners of the County of Cornwall.

GENTLEMEN, —The tin trade of the county of Cornwall is an object of such magnitude and importance that every Cornishman is actually, or virtually, interested in its success; therefore, every attempt to promote it is at least laudable, which it is hoped will be a sufficient apology for this address.

It is really difficult to account for the strange infatuation that has so long prevailed, relative to the mode of carrying on the tin trade, especially that part of it which is the subject now under consideration. The people of this county are by no means deficient in understanding, spirit, and activity on most occasions, yet they suffer themselves to be dictated to by their agents in London, and permit them to decide, and fix a value on the tin consigned to them, just as it suits their own interest, without consulting the interest of their employer, though the means of redress are always in their own hands.

The tin trade has long been in a languishing state, and will soon be in a much worse, unless speedy and effectual remedies are pointed out and applied. For the sake of the honour and reputation of the county, and still more for the sake of the poor industrious tinner, whose distress, great as it now is, must otherwise be greatly increased, it is necessary that proper measures be instantly adopted to prevent the impending evil.

I shall therefore proceed to show that the remedy is not only certain, but in your own power. Among the different causes of the present disagreeable state of this great staple commodity, *the first and great cause seems to be the lodging the tin sent to London and Bristol for sale in the hands of improper persons.*

The story of the farmer setting the fox to watch his geese is very applicable to my countrymen employing for their agent in the sale of tin, the pewterer, whose interest it is to keep down the price as low as he can—the lower it is, the more is his profit in manufacturing.

This is the root of the evil, and it is a matter of astonishment how a practice so inconsistent and absurd was ever introduced, but still more so that it should be persisted in, though the fatal effects of it are as evident as the sun at noonday, and are universally complained of, even by the persons who still continue to pursue this mode in spite of the voice of reason, interest, and common sense.

In truth, a certain great little man seems to have acquired the art of fascination, and to have attained such an ascendant over the minds of those who employ him to sell their tin, that neither the allurements of interest, nor the resentments which have frequently arose from his improper behaviour, are sufficient to break the charm, but he goes on to decide on the price of tin just as it suits his interest or caprice.

If no other persons suffered by this but those who employ such agents, the mischief would not be properly a subject of public discussion; but in fact, not only the whole body of tinners, but every man who has a landed estate in the county of Cornwall, is materially interested in the effect of this conduct, as the price of tin is now under the power and control of the pewterers, who raise fortunes at their expense.

To enumerate every particular that could be brought forward to elucidate this matter, is equally tedious and unnecessary: the fact is notorious, and the persons who have hitherto submitted to this disgraceful treatment are ready on every occasion to acknowledge it, and seem only to wish to know how they may get out of the toils in which they are involved.

The second cause of the present situation of this valuable trade arises from the dividing the tin sent for sale into too many hands.

One great mischief arising from this practice, is the giving the buyers an opportunity of going round to the different agents and spreading reports that such a person offers to make an allowance of one kind, and another of a different nature, and thereby creating jealousies amongst those who wish to sell the commodity with which they are entrusted at a reasonable price, and render a good account of sales to their employers. This being done, the consequence is, poor Cornwall is the sacrifice; down goes the price of tin, without even a shadow of reason for it: this I have known to happen repeatedly, and even the factors themselves (pewterers excepted) have lamented it, and owned there was no just reason for lowering the price of the commodity, and that not a block more would be sold on account of their reduced price.

To illustrate this by a recent fact. Last year a new duty of twopence per hundredweight was laid on tin exported, which was of course charged to the exporter, as all other duties were: but in London the dealers in tin first spread insinuations amongst the different agents that they could buy it without paying the new duty, and have at last insisted that it shall be borne by the tinner, and not by the exporter. A fact this, which speaks loudly the necessity of adopting some plan to remedy this and other evils of the same nature.

Other causes might be enumerated, but as the remedying those already mentioned will cure most of the subordinate evils, I shall only mention one more, which is the want of union amongst ourselves, in not fixing a general and reasonable price on the tin we send to London, and confining our agents strictly to the observance of our orders, and on no pretence permitting them to sell under the price agreed on.

This is so evidently a mischief, that it would be an insult to your understandings to attempt a formal proof of its being so. The only thing to enquire at present is whether any proper union subsists amongst the different persons who send tin to London and Bristol for sale. For the solution of this question I appeal to all persons interested in this trade who know and feel the fatal consequences of the want of union, and who will, I doubt not, be ready to adopt any durable and effectual plan which may be proposed to redress the present alarming condition of this once flourishing trade.

If the causes here assigned are founded in fact—and that they are so is too evident to need any further proof—the remedies for our distress are self-evident. The following short sketch of an association

for that purpose is submitted to your consideration; and, as I am informed, the Vice-Warden of the Stannaries has been requested to call a meeting* of the principal tinners, which he has promised to do as soon as he possibly can attend it. You will consider it in the meantime, and come prepared to make such additions and alterations as you may think most likely to promote the general good.

First, let us engage, and pledge ourselves to each other, that we will, on no pretence whatever, send or consign a block of tin for sale, to any pewterer, either in London or Bristol.

Secondly, Let us enter into an association, and have only four agents in London and two in Bristol; to one or other of whom we will consign all the tin we send for sale, and to no other person whatever. Let all tin so consigned be sold by each agent, rateably in proportion to the quantity he receives, without any preference; and let it be a positive order that the cargo that arrives first shall be sold first. Let the price at London and Bristol be governed invariably by the price in Cornwall, viz.: seven shillings per hundred above it, for all tin sold for home consumption; and upon what is exported let all additional duty and expense be borne by the exporter. Let our agents have a commission of one shilling per hundred; and let all tin be paid for on delivery, by an accepted bill, payable three months after date. Let our agents give such security, for the trust reposed in them, as may be thought adequate to it; and let it be resolved, that if either of the agents hath sold all the tin consigned to him, previous to the arrival of a fresh supply, he shall have a right to call on either of the others who have tin on hand, to supply his particular customers; and in that case, the commission shall be equally divided.

This, Gentlemen, is the outline of a plan, submitted to your consideration, by one who heartily wishes to promote the honour, interest, and happiness of his native country. The evils, proposed to be redressed, grow daily more and more unsupportable; the mode here recommended for redressing them seems obvious, easy, and in your own power. Exert yourselves, gentlemen, like Cornish men, and *one and all* unite to promote your own and your country's good, and no longer suffer your *Agents* to dictate to you as if they were your *Masters*; nor permit an insignificant pewterer to raise a princely fortune out of the distresses of the poor industrious tinner.

I am, Gentlemen,

Your faithful and obedient Servant,

CORNUBIENSIS.

* Since the above was printed, I see the Meeting is advertised to be held at Helston, on Friday, the 28th of January, 1780, which it is hoped every person interested will not fail of attending.

In the Appendix to this volume—in which it is intended to collect and tabulate all available statistical information on the trade in the metallic produce of these islands—will be found a general statement of the tin trade of Cornwall, and of the tin produced in other countries.

It is thought that by a well-digested arrangement it will be possible to construct a series of tables which shall be easy of reference, and at once show to the inquirer, the exact state of our mineral industries, at any period since records have been preserved. At the same time the text will be free from the encumbrances which usually offend the eye in the shape of tabular matter.

CHAPTER IV.

MINING FOR TIN AND COPPER TO A.D. 1800.

TIN.—Mining for tin and copper was carried on, in 1770, without any system of bounding. Permission was, at that time, obtained from the lord of the soil, and an acknowledgment—"dish," or "dues,"—was paid to him for permission to search. This was commonly one-sixth, one-seventh, one-eighth, or even to one-twelfth, or less. The dues for copper were payable in money, and those for tin in the stone or mineral, or in the metal called "white tin."

This grant by lease ran for one-and-twenty years certain. Pryce says, in 1778: "I do not suppose the present methods for working mines by deep shafts, and by 'driving' and 'stopeing,' under the firm ground has been practised more than three hundred years." This of course carries us back to the fifteenth century, and I am disposed to believe that we have indications of actual mining, by sinking shafts, and piercing the ground, by adits, or by levels, from a much earlier period.

Agricola, publishing his remarkable work in 1546, gives a considerable number of plates, which prove that mining had advanced beyond the mere digging of pits in his time. Numerous forms of machinery and tools, with implements, are given, all of which show that much thought had been devoted to the means necessary for the extracting, and also for the preparing, of the minerals raised, for the market. All this must have required the experience due to the influence of a long period of time.

About 1570 or 1580, Queen Elizabeth, as we have already stated, introduced a number of German miners into this country for the purpose of improving the British miners. Of course those men brought with them all the appliances which had been for a long period familiar to the miners of Saxony and Germany. Notwithstanding this, we find, in 1778, that no considerable advance has been made by the Cornish miners. With true Celtic obstinacy, they had remained satisfied with the methods used by their forefathers. We cannot do better than quote from Pryce his description of the mining operations with which he must have been familiar.

"*Bal*—spelt by Carew, *Ball*—is always in the singular number, with some adjunct to it, as Godolphin Bal, Ballanoon, Trevaunance Bal, &c., and signifies a parcel of tin mines—or working together—and has not the name from a valley—for many of them are very high. . . . Some, therefore, derive this word from the old British *Bala* or *Bal*, which, says Mr. Llhwyd (in his addition to Camden, in Merionethshire), signifies a village, or in old Irish, a place, as who would say, 'a place of tin;' others chose to derive it from *bali-pali*, to dig, *bal* or *pall*. This indeed seems to be the most natural derivation."

Lord De Dunstanville adds: "If we consider the different ways of expressing themselves, this will appear to be right. When you ask a tinner in the morning where he is going, he will answer you, 'Going to moore,' if to a *stream work;* but if to work in a *mine*, he varies his phrase, and tells you he is 'going to bal,' to let you know he is going to dig."

"Prior to these means for mining tin—that is, by shafts and underground levels," Pryce says, "they wrought a vein upon the 'bryle' (*i.e.* upon a disturbed piece of ground, supposed to be the outcrop of the mineral vein,—a disordered mass. I believe it was originally intended to express an idea that the lode had 'boiled' over at this place) to the depth of eight or ten fathoms all open to grass (that is the surface), very much like the 'fosse' of an intrenchment. This was performed by mere dint of labour, when men worked for one-third of the wages they now have. By that method they had no use for foreign timber, neither were they acquainted with the use of hemp or gunpowder. This fosse they call a 'coffin' (some good examples of these 'coffins' are still to be traced in many mines, as in Providence mines, St. Ives—in Polberro, St. Agnes, in the mines in Baldhu—and at Drake Wales, near Calstock), which they laid open several fathoms in length, east and west, and raised the tin stuff on '*shammels*'—plots or stages six feet high from each other till it came to grass. Those shammels, in my apprehension, might have been of three kinds, yet all answering the same end. First they sunk a pit one fathom in depth and two or three fathoms in length, to the east and to the west of the middle of the lode discovered; then they squared out another such piece of the lode for one or two fathoms in length as before; at the same time others were still sinking the first or deepest ground sunk, in like manner. They next went on and opened another piece of ground each way from the top, as before, while others were still sinking in the last, and in the deepest part likewise; in this manner they proceeded step after step, from which motion arises the modern method of '*stopeing*' the bottoms underground. Thus they continued sinking from '*cast*' to '*cast*,'—that is, as high as a man can throw up the tin stuff with a shovel—till they found the lode become either too deep for hand work, too small in size, very poor in quality, or too far inclined from its underlie for their perpendicular workings. Secondly, if the lode was bunchy, or richer in one part than another, they only laid open and sunk upon it, perhaps in small pitches not more in length than one of the 'stopes' or 'shammels' before described. The shortness of such a piece of lode would not admit of them sinking stope after stope; it was then natural and easy for them to square out a shammel on one side or wall of the lode, and so make a landing-place for their tin stuff, cast after cast. Thirdly, if the lode was wide, and the walls of it and the adjoining country very hard, solid ground, it was in such case more easy for them to make shammels or stages, with such timber, &c., as was cheapest and nearest at hand."

The following, also from Pryce, sets forth in the simplest and clearest manner the method of working a mine in the eighteenth century:—

"We shall now set forth the first arrangements for working a mine, in order to which, the principal thing to be thought of is a shaft to cut the lode at twenty or thirty fathoms deep, if it is possible to be done. Here it is

necessary to form some judgment of the inclination or underlie of the lode, before we attempt to sink a shaft; for instance, if the lode underlies to the north about three feet in a fathom, and a shaft is designed to come down upon the lode in twenty fathoms sinking, the miner must go off north from the back of the lode full ten fathoms, and there pitch his shaft, by which means he is certain to cut the lode in the shaft about twenty fathoms deep; because for every fathom the lode descends in a perpendicular line, it is also gone three feet to the north of the perpendicular.

"A proper working shaft, upon which a *whym* may be erected if necessary, should be six feet long and four feet wide, or more where large water barrels are wanted; and the harder the ground is, the longer and wider the shaft ought to be, that the men may have the more liberty to work and break it, the area of a large shaft being more easy to rip up where the ground is hardest than of a small one where it is more confined together and breaks in shreds of stone, &c.

"A shaft that is designed for a water-engine may serve, if it is of the size of the largest working shaft, but a fire-engine shaft ought to be at least nine feet square, or ten feet by eight, or, in fact, to contain three shafts in one, which must be partitioned into three compartments, all the way down from grass to the deepest bottom of the mine. One-half is divided for the pumps and engine-work; three feet in length of the other is proportioned for a foot-way, to go down and rectify the pumps when amiss; and the remainder is divided also by a partition of boards for a whym-shaft to draw the deads and ore from the sump of the mine. If the ground is hard and very wet, or the water very quick upon the men in sinking, there ought to be eight men employed to sink a working shaft; that is, two men in a corps of every six hours, and in a fire-engine shaft there should be sixteen employed in the same manner; but if the ground is tender, and there is no hindrance by water, six men in the first, divided into three corps every eight hours, are reckoned sufficient; yet I have known four-and-twenty men put to sink an engine-shaft upon emergency.

"The working shaft being sunk downright until it cuts the lode, they open the vein, or sink the body of the shaft through it; and if they think the vein is worth following, they sink the same shaft deeper in the body of the lode, upon its inclination or underlie; whence the shaft becomes, and bears the name of an *underlier*. At the same time they '*turn house*,' as they call it, from the bottom of their perpendicular, or from the top or beginning of the underlie. So that when the lode is well impregnated, they turn house by driving or working horizontally on the course of the vein either to the east or to the west, or both, as they find it most likely to answer their expectations, in order to make a fuller trial and discovery. Where the lode answers well in thus driving upon it, they continue to do so till they are prevented by want of air, or till the end of their workings is too far from the shaft, and the expense of rolling back the stuff to the shaft is great and incommodious; then it is proper to put down another shaft as before described, or more to the north, because it will be more convenient the longer it continues downright. Meanwhile, they are mindful to sink their first shaft in order that they may work away the lode from thence in stopes, and have

a little *sump* or pit in that place as a basin for receiving the water of the lode, whence they discharge it to grass by the easiest method they can devise; for most lodes have streams of water running through them; and when they are found dry, it seems to be owing to the waters having been forced to change their course, either because the lode has stopped up the old passage, or because some new or more easy ones are made, whereby the lode and strata adjacent to it are *bleeded*, as we term it. However, they are often hindered from going down deep enough to find any great quantity of ore by the burden of water that most veins abound with; therefore, if the mine is not encouraging, they give over any further pursuit; but if it seems likely to prove well, and the lode lies in an ascending ground, they quit the vein for the present, and go down to the most convenient place in the valley, and from thence they bring a French-drain or conduit—which they call an *adit-tye* or *level*—and so they work and drive this passage through the hill in a right-line to the lode, with very little loss of the level they began from. Where the adit is intended only for the sake of unwatering one particular vein, it is frequently advisable to bring it home on the course of it, if the situation of the ground will admit, because this is a continual trial of it at that depth; yet, if there are many lodes not far asunder, an adit burrowed home athwart them may sometimes be preferable, if it can be conveniently complied with; for the situation of the ground must be well considered, to judge how to drive home the most short, deep, speedy, and cheap adit, and with the most probable success. These adits are commonly six feet high, and about two feet and a half wide, so that there may be room enough both in height and breadth to work in them; and, also room to roll back the broken deads in a wheelbarrow; but, if the ground or rock be very hard, the adit ought to be more spacious or large each way, to give the greater liberty or room to work and break the stone. An adit requires four men to work it constantly by day and night, and a boy or two to roll back the broken work if they break it very fast. When the miners want air by being a great way underground, and cannot conveniently put down a new shaft, then, if the adit be high enough, they lay boards at the bottom of the adit from their last shaft along to the adit end, and so stop them down closely with clay or earth, by which contrivance, called a *saller* (or soller), the boards being hollow underneath, air is conveyed to the workmen.

"The *air-pipe* (a pipe with a funnel-shaped head which can be turned to the wind when it blows from any quarter) is seldom used in adits because the saller is more cheap and easy, the difference of expense in the air-pipe being considerable where an adit shaft is thirty or forty fathoms deep; beside, the saller under the workmen's feet is less incommodious than the funnel over their heads.

"I have known an adit-end driven several fathoms at four shillings a fathom, in Pot-*grouan*, that is, soft *grouan*; yet I have paid twelve guineas for the same adit that we have driven many score fathoms for less than one; so various and uncertain are the strata of the earth in these parts. The greatest expense for the ground discovered that I ever heard of in driving an adit was in the Old Pool Mine (about two miles from Redruth), where Mr. Basset paid

five-and-thirty pounds for the driving of several fathoms through one free-stone strata."

Pryce continues with sundry remarks, mainly in praise of the perseverance of the Cornish miners, and on the advantages frequently derived from the liberal expenditure of time and money. He then proceeds to show that the miners cannot go far below the adit without having recourse to some contrivances to remove the water from their workings. He then enumerates the hand-pump and the force-pump, which he says will do very well for small depths: "Next to these the water is drawn to adit, by small water-barrels, but if the water exceeds a certain number of barrels in the course of six or eight hours, they give over drawing by hand, and erect a *whym*, which is a kind of horse-engine to draw water or work, and sometimes both, especially in the infancy of a mine."

"Another water-engine—then frequently used—was the *rag-and-chain*, which was constituted of an iron chain with knobs of cloth stiffened and fenced with leather, seldom more than nine feet asunder. The chain is turned round by a wheel of two or three feet diameter, furnished with iron spikes, to enclose and keep steady the chain, so that it may rise through a wooden pump of three, four, or five inches bore, and from twelve to twenty-two feet long, and by means of the leather knobs bring up with it a stream of water answerable to the diameter of the pump, and in quantity according to the circumlocution of the wheel in any given time. A rag-and-chain pump of four inches diameter required five or six fresh men every six hours to draw twenty feet deep. The monthly charge of one of these engines was not less than £50 to £60 a month; and they are now pretty generally laid aside, on account of the great expense and the destruction of men. Nevertheless, the motion of the rag-and-chain, when it is constant, is so quick, that it will discharge a quantity of water, even exceeding that of a wheel-and-bob engine, whose pump is ten inches bore; and it may be usefully applied to draw water from sundry parts, such as *dippas*—or little pits of a mine—which have no communication with other machinery for the delivery of the water to the adit. A water-wheel with bobs is yet a more effectual engine." We learn from Mr. Pryce that the water-engine wheel at Cooks' Kitchen mine was forty-eight feet in diameter, and worked her tier of pumps of nine inches bore, which, first divided into four lifts, drew from eighty fathoms under the adit. The scarcity of water in those days was much complained of by the miners. "Happy would it be for the mining interest, if our superficial streams of water were not so small and scanty; but the situation of our mines, which is generally on hilly grounds, and the short current of our springs, from their source to the sea, prevents such an accumulation of water as might be applied to the purpose of draining the mines; and of course the value of the water is the more enhanced." When, in those days, the situation of a mine would not admit of a water-engine, or where the stream is insufficient, "the last resource is that most useful, powerful, and noble machine—the *fire-engine*, of which we have several that are perhaps the largest in the kingdom" (*Pryce*, 1778).

Mr. Joseph Carne states that the first steam-engine in Cornwall was

erected at Wheal Vor, a mine at work from 1710 to 1714. This appears to have been on the plan of Captain Thomas Savery.* "The Marquis of Worcester, in his 'Century of Inventions,' published in the year 1663, is probably the first that proposed converting water into steam; but Captain Savery was the first who erected an engine for this purpose, which has been lately improved by Mr. Blakey, though not to a degree of power sufficient to unwater a deep mine" (*Pryce*).

Newcomen's patent for his atmospheric engine was granted in 1705; but his engines do not appear to have been much known before 1712. Mr. Pryce informs us that Mr. J. Cawley was associated with Mr. Newcomen, and that they "contrived another way to raise water by fire: where the steam to raise the water from the greatest depths of the mine is not required to be greater than the pressure of the atmosphere; and this is the structure of the present fire-engine, which is now of above seventy years' standing." Pryce then enters into a long description of Newcomen's engine, and mentions several improvements which had been introduced, and he gives a very useful table of the calculation of the power of fire-engines, for the various diameters of the cylinders and bore of the pump or pit-barrel, that are capable of raising water at any depth between 2 and 876 fathoms. This was calculated out for him by Mr. John Nuncarrow, jun.

Newcomen's engine was found to be very costly, from the quantity of coal consumed. Mr. J. Carne explains, that "notwithstanding numerous contrivances to diminish the cost of the coals consumed in these engines, among which there was one of a granite boiler heated by means of three tubes passing through it, the consumption of fuel was still great, and estimated at £3,000 per annum for engines of large size."

COPPER.—It is impossible to determine with accuracy when copper ore was first worked in Cornwall. Bronze vessels, weapons, and tools have been constantly found in Cornwall; but there is no evidence existing to show that either bronze or brass were manufactured in that county. Notwithstanding, the fact exists, that copper, tin, and zinc are found abundantly in the mineral lodes which traverse the Cornish rocks. It scarcely appears possible that the detrital deposits of tin should have been worked from the earliest times, without the discovery of the mineral veins from which the stream tin had been derived. If so, they would have been subjected—and probably were so—to the process of mining, and the copper ore, which is so frequently disseminated in the same vein containing the tin, must have been discovered, and, if discovered, it would assuredly have been melted. It is not a little strange that, with all the attention which has been given to the early history of tin mining, there are to be found only a few very brief and unsatisfactory records of the discovery of copper.

The late Colonel Grant Francis has, with much industry, collected from the stores of the Record Office considerable information, relating especially to the commencement of copper smelting in the Swansea district. From the

* "Transactions of the Geological Society of Cornwall," vol. iii. p. 50; see also "The Miner's Friend; or, an Engine to raise Water by Fire, described, and the manner of fixing it in mines; with an account of the several other uses it is applicable unto, and an answer to the objections made against it." By Thomas Savery, Gent. 1702.

letters and other documents published by him, we gather some information respecting the copper mines of Cornwall.*

On the 15th January, 1583, Mr. William Carnsewe writes to Mr. Smith, commending "Mr. Weston's p'vydence in bryngyne hys Dutche myners hether to aplye such busynys in this countrye," that is, the smelting of copper and lead. The writer then requests that Mr. Weston's Germans may have some men "assignyd only to them, and lett yo'r Ulryke (one Ulrick Frosse) take such as he is now acquaintyd with of our countrymen; and the sam that wreought in that work at Treworthye last when it was by Burchardys' frowardniss gyvyn ov'r, w'che was abowte 23 yerys past." Thus we learn that smelting operations on a fairly large scale were in action before 1560, and a thousand marks were allowed to Ulrick Frosse "for erectynge yo'r meltynge howsys, and woody's for cole and fewell."

We learn subsequently that Ulrick Frosse was made, in 1584, "Overseer of the Mineral Works at Perin-Sands," &c., in Cornwall. This fixes the site of smelting works at Perranzabula, or Perran-on-the-Sands, very early. In another letter we are told that H. Herring obtained "the owrs for xvs. the tonne, whereof iiii. tonnes will make one tonne of copper. . . . . The fear the partners have, is that we shall not gett owre in any great quantitye to raise worthy co'moditye. . . . . It appeareth y't yow have not above 50 tons gotten in all, w'th ye w'ch you have to get 20 tonnes more before Michaelmas next."

At this time we are informed that "the new melting-house at Neath, in Wales, is ready," and that "one of o'r copper makers, with an under-melter and ye Douch carpenter, shall be sent from Keswick," to commence operations.

Ulrick Frosse, writing to Mr. Smith on the 22nd July, 1584, says: "Mr. Carnsewe was here the xi. of July laste paste to se o'r workes, o'r myne here at Perin-Sande, and wente downe with me into the bottom of the works, and so up alongste the new audict we made, w'ch is at this present above 50 fadom longe, under all ye olde workes, but we do not lighte w'th any owre as yet; with greate springs of water we lighte still in going up, w'ch will put me to great charge in the end, I fear me. We have yet above 17 or 20 fadom to the deepe shafte where the most owre was left by report, to which we thinke to com about the latter end of Augustee, with God's helpe."

This evidently indicates that the company which Mr. Carnsewe represented had taken up an old working, and that the promises of profit were very unfavourable. It is not possible to fix with any certainty the mine of which this letter speaks. It was, probably, Perran St. George. The previous letter informs us that copper ore was raised at 15s. the ton, and that it was very rich ore, giving 25 per cent. of copper. The quantity of copper ore obtained was evidently very small. In another letter we read, "Wee did light w'th a lyttle ewre at Treworth, the quantitye of all most on C waight in one nest by itself, but cut sune out again."

Ulrick Frosse is removed from Cornwall, and becomes "Melting Master"

* "The Smelting of Copper in the Swansea District, from the Time of Elizabeth to the present Day." By Colonel Grant Francis. (Southern and Co. 1881.)

at Neath. He writes from that place, saying that the smelting operations, "thank God, doth goe reasonably well forward, and lak but only good store of riche owre." On October 27th, 1585, one John Otes writes: "The 14th of October came John Bwaple, one of Wales, with his bark for a fraygte of copp' owre, and did deliver him, the 21st of October, 15 tonn and 8 hundred of copp' owre for Wales. The 15th October came one Thom's Roberts from Wales, from the company, w'th a fraight of tymber and necessaryes for the workes. I receaved his fraight at St. Ives, and for my lyffe I could not get any owre from St. Yeust (St. Just) to St. Ives, to fraight him for Wales (Neath), but went away w'hout any, for Bwaple would carry more owre yf I had it at St. Ives." *

This clearly proves that the quantity of copper ore worked in Cornwall at this time was very small. On the 7th March, 1586, Ulrick Frosse writes Mr. Carnsewe: "We looke dayly for the copper refiner from Keswicke, and have in readiness as much copper roste and blake copper as will make a 20 tonne lot of good fine copper." The writer in another part of the same letter says, "We will melt in the space of 7 houres the quantitie of 24 C of ewre, and spend not above 8 or 9 seks of chare-coles and three horslod of sea coles, and if the ewre be well and clean sorted, the more copper stone will it yield; melting many sorts of ewre together is the most proffet, and will melt a greattayal sooner."

CUMBERLAND.—The Keswick Copper Works were founded in 1566, a company being incorporated for the purpose of working Goldscope and Dale Head mines for copper ore.

The extensive copper smelting-works erected in 1566 were said to be the largest in Europe. Six furnaces were in operation in 1567, chiefly supplied with ore from the mines in Newlands. This work was carried on by a colony of Germans, the chief manager being one Hockstetter. In 1539 a plot of ground was purchased from Mr. Curwen, of Workington, and a wharf was built for the use of the mines and smelting-works. These continued in active operation until 1650 or 1651, when they were destroyed during Oliver Cromwell's campaign in the north. They were partly rebuilt by a company of Germans about 1690, and continued working until 1715.

Goldscope has been an important copper mine since the early part of the thirteenth century; being mentioned in the Close Rolls of Henry III. Camden says:† "At Newlands and other places some rich veins of copper, not without a mixture of gold and silver, were discovered in our age, A.D. 1607, by

* That the name (which is improperly written St. Ives for St. Ies, no one in the least conversant in the antiquities of our country can make the least doubt of) is taken from St. Iā, I shall not now bestow my time to prove this, for this town is to this day called by the common people in the West, *Porthia* (St. Iā's Port). Leland particularly describes this town in his "Itineraiy."

"The parish church is of Iā, a nobleman's daughter of Ireland, and disciple of St. Barricius. Iā and Edwine, with many others, came into Cornwall and landed at *Pendinas*. This Pendinas is the peninsula and stony rock where now the town of St. Ies standeth. One *Dinan*, a great lorde in Cornewaule, made a church at Pendinas at the request of Iā—as it is written in St. Ies legend," &c. (*Tonkin.*)

The peninsula spoken of is now called "The Island," and there is unmistakable evidence that it was an island at one time, and by that name it is distinguished in the map of the Ordnance Survey. The island proper must be regarded as a mass of Greenstone, but the small neck of land which connects it with the present town, is chiefly Devonian slate, overlaid by a remarkable *Raised Beach*, which clearly indicates that at one period the sea flowed over this portion of land.

In all probability this "island" was one of the many around the Cornish coast to which the name of *Ictus* was given by Herodotus.

† Gibson's "Camden Britannica."

Thomas Thurland and David Hockstetter, a German of Anspurg, though known, many years before, as appears by the Close Rolls of Henry III." About these mines there was a memorable trial between Queen Elizabeth and Thomas Percie, the Earl of Northumberland, on the question of its being a "Mine Royal," and it was decided in the Queen's favour.

Robinson,* writing in 1709, says: "In our survey of the mountains of Newlands we found eleven veins opened, and wrought by the Germans, all distinguished by names given to them, as Gowd-Scalp—now Gold-Scope—Long Work, St. Thomas's Work, &c., these being at Dale Head, about a mile and a half south of Goldscope, of all which veins were found to be the richest. We found the vein wrought three yards wide and twenty fathoms deep above the grand level, which is driven in a hard rock a hundred fathom, and only with pickaxe, hammer, and wedge, the art of blasting with gunpowder being not then discovered. For securing of this rich vein no cost of the best oak wood was spared, and for the recovering of the solers under the level was placed a water-gin, and water was brought to it in troughs of wood upon the tops of high mountains near half a mile from the vein."

The Goldscope mine was abruptly closed in 1651, and most of the miners were killed, or drafted into Cromwell's army. Clarke, in his "Survey of the Lakes," says that the Dutch, who came with the Prince of Orange, about 1690, began the work again, and continued it until they were driven from it in 1715. They appear, however, to have opened the mine subsequently, for Clarke says "they stayed until the place was not worth working."

The above passages prove the existence of copper mines—or rather of a considerable smelting establishment, at Keswick, in Cumberland, before 1586. This appears to have belonged to the Earl of Northumberland.

Dr. Percy writes:† "In the time of Elizabeth (1558 to 1602) there was a rich copper mine at Keswick, in Cumberland, of which that Queen deprived the Earl of Northumberland, on the ground that it was a Mine Royal. It is reported that not less than four thousand men were employed at this mine, but this is probably a great exaggeration." It is certain that in the time of Edward III. copper mines were worked at Skildane, in Northumberland, and at Alston Moor, in Cumberland. This will carry copper mining back to before 1377, when Edward ceased to reign. In the fifteenth year of his reign, that was in 1541, this King granted for fifteen years the right to work a mine of copper at Richmond, in Yorkshire, on payment of a royalty to himself of one-eighth, and one-ninth to the lord of the soil. It appears to have been a usual custom in those days to smelt the copper ore near the mines, but from there being a considerable establishment at Keswick, we may infer that ore was gathered from the copper mines of the counties adjoining Cumberland, and smelted at Keswick as a convenient centre. It is evident that the smelting-works at Keswick were fairly organised, for in July of 1585, Ulrick Frosse writes, boasting "as to melting 24 cwt. of ore every day, with one furnace, God be thanked;" and they were enabled, he says, to send in the previous year "the copper refiner, the copper maker, the

* Robinson's "Natural History of Westmoreland and Cumberland."

† "Metallurgy," p. 289. By John Percy, M.D., F.R.S. 1861.

under-melter, and the Dutch carpenter, to serve" at the new melting-house at Neath, in Wales. From 1580 there appears to have been a continued importation of German miners and melters. Amongst them we find, as managers—

Marcus Steinberger,
Richard Ledes,
Emanuel Hechstetter, or Hockstetter,
Ulrick Frosse,
Jochim Gaunse,
Daniell Houghsetter,
Christopher Schutz.
Thomas Thurland.

It is curious and interesting to find in a "Description of the Doeings of Jochim Gaunse and George Needham, at the copper mynes by Keswicke in Cumberland, A.D. 1581," "the nature and the number of the hurtful humours that were naturally bred in oure copper owre gotten in that countrie.

"The names of the ix. infectyve and evill humours:—

"1. The first is sulphur, being a mineral substance which verie quickly taketh fre, and wil be consumed in smoke by blast, &c.*

"2. The ii. corrupt humour is arsenique, by nature a kind of poyson, being in like manner a mineral substance, wil be consumed with fire into smoke, which is a very dangerous ayer or savor, and by his force maketh the copper white and brether than the sulphur doeth, &c.

"3. The iii. corruption is antimony, w'ch is in like manner a mynerale substance, and by roasting wil be consumed into smoke, &c.

"4. The iiii. corrupt humour is *vitriall*, in like manner a mynerale substance, and if the force thereof be not corrected by roasting, . . . it fretteth the copper and maketh it bretle and black coulered," &c.

(Although George Needham displays in this, his very imperfect chemical knowledge, yet we find by his rude experiments he arrives at a method for removing this vitriall, and "thus is this vitriall of an enimye made a friende.")

"5. The v.th corruption is *calcator*, being the mother or corpus of vitriall, and a mineral substance," &c. (This is, undoubtedly, "calcother," the old name for oxide of iron.)

"6. Allom is the vi.th corrupt humour, a myneral substance, and by nature a let to ye smeltinge of copper.

"7. The vii.th humour is iron, being one of the vii. metals, but no mynerale, &c.

"8. The viii.th hurtful humour that is in our copper ore is a kind of *black stone*, wherein the copper is bred and doth grow.

"9. The ix.th and the last corrupt humour is a kind of white stone, called sparr," &c.

The 8th and 9th "humours" are clearly rock in which the copper is found and the quartz found in the lode.

In connection with the smelting-works at Keswick we find:—

"Whereas Mr. Steinberger, at his last being in London, made his propo-

* In each case it appears sufficient to give but a small part of the description.

sition to the company (March, 1582), that for everie quintall of rough copper he made (being cxii. *li*), he must have vii. kebulls* of copper ore gotten in "God's Gift mine,"† everie kebull whereof is in waite clv. *li* at the least, w'ch, after a cxij. *li* to the hundredth, amounts to x. *c* iiij. *xx* v. *li*‡ of ore, and for all manner of charges of fireworke and smelters' wages to bring the same x. *c* iiij. *xx* v. *li* of ore into rough copper, he offereth to do it for xiii. *s*. iiij. *d*."

At these works we learn that they had acquired the process of separating the iron from the copper in the condition of a sulphate. The writer says: "And yf ye cannot have utterance of so much *vitriall* as we can make, then may we make of that substance *copperis*—which we shall make for the dyeing of cloth—without taking any copper from the ure. . . . . For vent of this coppris ther wil be great quantitie used in Cumberland, Westmoreland, Yorkshire, Cheshire, and Lancashire only for dyeing, who are constrained to transporte it from London thether. And likewise ther wil be much soulde into the North parte of Scotlande, who have often tymes both come and sent to Keswick to buy coppris." There follows much speculation as to the sale of this sulphate of iron in France and Spain.

Mr. George Needham, in the same letter, speaks "of the rich copper ure gotten in the mines of Caldbeck being infected with such corruptions that hetherto Mr. Danyell and his sonne could never melt them alone as they came from the myne, but were forced to myngle with them roasted ure of the first melting of 'Gode's Gift' ure." Again, the imperfections of the works or the ignorance of the workmen is shown, as—"In like manner the rich lead myne at Caldbeck, which houldeth good quantity of silver, and hath costt he company great sommes of money, lieth now unwrought."

Queen Elizabeth, by her letters patent, in the sixth year of her reign, on the 10th day of October (1564), did grant "full power, license, and authority to Thomas Thurland, clerk, one of the chaplains and Master of the Hospital of the Savoy; and to Daniell Houghsetter, a German born, and to their heirs," &c. &c., permission "to search, dig, open, roast, melt, stamp, and wash, drain or convey waters, or otherwise work for all manner of mines or ewers . . . within her counties of York, Lancaster, Cumberland, Westmoreland, Cornwall, Devon, Gloucester, and Worcester, and within her principality of Wales.

"Her Hyghnes too have for the first vi. years then next, the x.th part of all the pure metals or ures of golld, sylver, and quicksylver, and of every C weight of mixt ure holding viii. *li* or above of those rich metals to have all the x.th part. And of Tynn, in the name of coynage, as her Ma'ti hath in Devon and Cornwall, and of lead as in other places of the realm, and of the Calamine the xx.th pt. or just value thereof. And of every C of copper for the said first vi. years ii.s., or the xx.th part at her lykyng; and after those vi. years ii.s. vi.d., or the xv.th part or value at chois aforesayd."

This document was endorsed "unto the Right Honourable Sir Francis Wallsingham, Knight, one of the twoo Principal Secretaries, unto the Q. Ma'ti."

On the 22nd day of January, in the next year (1565), a similar "confirmatory charter" to one previously granted by Elizabeth was given to the

* The same name, now spelt *kibals*, is given to the iron buckets in which the ore is raised to the surface.
† The name of one of the mines of Caldbeck.
‡ Ten hundredweight fourscore and five pounds.

"Mineral and Battery Works." With this, as being a purely metallurgical company, we have less concern. It is important, however, to notice the continued introduction of the German element. James I., in the second year of his reign, A.D. 1604, on the 28th day of January, granted a charter confirmatory to the Mines Royal Society. This charter commences: "Whereas our dear late sister Elizabeth, late Queen of England, having received creditable information that her faithful and well-beloved subjects, William Humphrey, and her Say Master of her Mint within the Tower of London, by their great endeavour, labour, and charges, have brought into her realm of England one Christopher Shutz, now deceased, an Almaigne, born at St. Annenberg, under the obedience of the Elector of Saxony, a work master, as it was reported, of great cunning and experience, as well in the finding of the Calamine Stone, called in Latin *Lapis Calaminaris*, and in the right and proper use of the commodity called 'Laten,' and in reducing it to be soft and malleable, and also in orpting, mannering, and working the same for and into all sorts of battery wares, cast work, and wire, and also in the mollifying and mannering of iron and steel, and drawing and forging of the same into wire and plates, as well as convenient and necessary for the making of armour, and also for divers other needful and profitable uses."*

Those German miners were the first to introduce into this country the mystery of the Divining Rod. Borlase says, "Few of the Cornish have ever heard of the *Virgula Divinatoria* and its virtue in discovering metallic lodes."

Pryce, in his "Mineralogia Cornubiensis," himself a believer in the virtues of the Divining Rod, commonly called in that county the "Dowsing Rod," writes: "Hooson says that 'the first inventor of the *Virgula Divinatoria* was hanged in Germany as a cheat and impostor.' On the other hand, Dr. Diederick Wessel Linden says, in answer to him, that Dr. Stahl, when he was president of a chemical society in this country, published a reward of 25 ducats for anybody that could prove who was the inventor of the *Virgula Divinatoria*."

He then goes on to inform his readers that "Georgius Agricola, in his excellent Latin treatise, 'De re Metallica,' says 'that the application of the inchanted or divining rod to metallick matters took its rise from magicians and the impure fountains of inchantment.'"

The Rod of Aaron and the rods of the Egyptian sorcerers, Mercury with his rod *Caduceus*, and several other examples, might be quoted from which the forked rod of the searcher for mineral veins, and for water, took its rise.

No mention is made of the divining-rod of the miner before the eleventh century, since which time we often hear of it. It was much used in France and Germany in the seventeenth century. The corpuscular philosophy was made to account for the phenomena. The corpuscules—infinitely minute particles—were thought to rise from the mineral veins, and, entering the rod, determine it to bow down, in order to render it parallel to the vertical lines which the effluvia describe in their rise. "In effect, the mineral particles seem to be emitted from the earth. Now the *virgula*, being of a light porous wood, gives easy passage to those particles, which are very fine and subtle.

* These Confirmatory Charters are printed in full by Colonel Francis, in his "Smelting of Copper in the Swansea District."

The effluvia, then driven forward by those that follow them, and pressed at the same time by the atmosphere incumbent on them, are forced to enter the little interstices between the fibres of the wood, and by that effort they oblige it to incline, or dip down perpendicularly, to become parallel with the little columns which those vapours form in their rise" (*Pryce*).

Dr. William Cookworthy, of Plymouth, well known for his discovery that the Kaolin of the Chinese was the China clay of the Tregoning and Godolphin hills of Cornwall, gives an account of his first knowledge of the divining-rod. The rod was introduced to him by a Captain Ribeira, who deserted from the Spanish service in Queen Anne's reign, and became captain-commandant in the garrison of Plymouth. "In which town," says Cookworthy, "he satisfied several intelligent persons of the virtues of the rod by many experiments on pieces of metal hid in the earth, and by the actual discovery of a copper mine near Oakhampton, which was wrought for some years." The captain made no difficulty about letting people see him use the rod, but he was absolutely tenacious of the secret how to distinguish the different metals by it, without which the knowledge of its attraction was of little use. Pryce says he has discovered this, and made many other discoveries of its properties, which he is willing should be published, being fully persuaded of the great utility of this instrument in mineral undertakings.

Agricola writes: "If the *attractive power* of veins does not turn the rod, when in the hands of some particular metallists or others, it is owing to some singular occult quality in the holder, which impedes and restrains the attractive power; for since that power moves and turns the rod in the same manner as the loadstone invites and attracts iron, it is debilitated and destroyed by the occult quality of the holder, just as garlic weakens and excludes the attractive quality of the magnet, for a *magnet rubbed over with the juice of garlic does not draw iron*." * This is a statement which has no foundation in fact.

Unless where it is stated to the contrary, the following descriptions and directions, representing the custom of the country, are derived from Pryce.

The rod is attracted by all metals, but with different degrees of strength, in the following order:—1, gold; 2, copper; 3, iron; 4, silver; 5, tin; 6, lead; 7, coal; 8, Limestone and springs of water. Pryce gives the following experiment. Stand holding the rod, with one foot advanced; put a guinea under that foot and a halfpenny under the other. The rod will *be drawn down*. Shift the coins, and the rod will be drawn towards the face or backwards to the gold, which proves the gold to have the stronger attraction.

The divining-rods formerly used were shoots of one year's growth *that grew forked*; but two separate shoots tied together with some vegetable substance, as packthread, will answer better than those which are grown forked. As the shoots are seldom of equal length or bigness, they do not handle so well as the others, which may be chosen of exactly the same size. The rods should be between two and three feet long. They must be tied together at their great or root ends, the smaller being held in the hands. Hazel rods cut in the winter, such as are used for fishing-rods, and kept until they are dry, appear to answer the best. Apple-tree suckers, rods from

* Georgii Agricolæ, "De re Metallica." Basileæ, MDLVI.

peach-trees, currants, or the oak, though green, will answer tolerably well. Of late years a forked twig cut from a black thorn has been regarded as the most sensitive rod. Pryce says it is difficult to describe the manner of holding the rod, so he has given an illustrative drawing, which we copy, Fig. 11. We shall endeavour, however, to give some idea of the mode of holding the rod.

The operator stands with his arms extended and the hands wide open; an assistant places the twig, or arm of the fork, in each hand, flat upon the palm; the four fingers of each hand are now closed upon the ends of the fork. It is perfectly easy thus to hold the rod; but although in the drawing given from Agricola, Fig. 10, it does not appear as if the rod was held in any particular manner, the drawing given by Pryce shows the difficulty of adopting the proper position. The four fingers being closed upon the rod, and the rod held firmly, without allowing it to move, the point is by a movement of the hand turned up towards the face, and then down and round, so that the point of the rod is in front of the operator. It will, we think, be evident from this that a very severe twist or strain is given to the wrist, and that consequently the rod is held in a state of extreme tension. With the arms in this condition, and with the mind fixed on the discovery of a mineral vein, the operator becomes conscious of a slight tremor, the result of muscular action. The muscles, by an automatic effort, endeavour to relieve themselves from the strain. There is a tendency, too, in the first instance to resist this, and consequently the fork of the rod is moved either up or down, and it is declared to be active. Even in Pryce's drawing the constrained position of the hands is only indicated by the flexure of the rod.

Fig. 10.—Facsimile from Agricola.

With the figures we hope the above description may serve, especially after reading the following extract from Pryce: "The rod being properly held by those with whom it will answer, when the toe of the right foot is within the same diameter of the piece of metal, or other subject of the rod, it will be repelled towards the face and continue to be so, while the foot

is kept from touching, or being directly over the subject, in which case it will be sensibly and strongly attracted and be quite drawn down. The rod should be firmly and steadily grasped; for if when it hath begun to be attracted there be the least imaginable jerk or opposition to its attraction, it will not move any more till the hands are opened and a fresh grasp taken. *The stronger the grasp the livelier the rod moves*, provided the grasp be steady and of an equal strength. This observation is very necessary, as the operation of the rod in many hands is defeated purely by a jerk or counter-action, and it is from thence concluded that there is no real efficiency in the rod, or that the person who holds it *wants the virtue*; whereas by a proper attention to this circumstance in using it, five persons in six have the *virtue, as it is called*—that is, the nut or fruit bearing rod will answer in their hands. When the rod is drawn down, the hands must be opened, the rod raised by the middle fingers, a fresh grasp taken, and the rod held again in the direction described."

Pryce continues, giving some instructions which are entirely at variance with the hypothesis that electricity, magnetism, or any such force is active

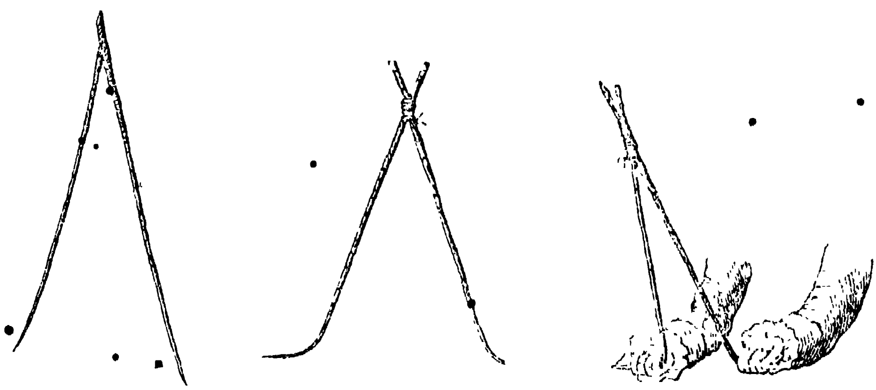


Fig. 11.—The Divining-Rod.

in producing the phenomena. "If a rod, or the least piece of one, of the nut-bearing or fruit kind, be put under the arm, it will totally destroy the operation of the *Virgula Divinatoria* in regard to all the subjects of it, *except water*, in those hands in which the rod naturally operates. If the least animal thread, as silk, or worsted, or hair, be tied round or fixt on the top of the rod, it will in like manner hinder its operation; but the same rod placed under the arm, or the same animal substances tied round or fixt on the top of the rod, will make it work in those hands in which, without these additions, it is not attracted. All rods, in all hands, answer to springs of water."

The same author tells us that gold or copper held in the hand hinders the rod from being attracted by either of those metals. If iron, silver, lead, or tin be held in the hand, the rod will not be attracted by these metals, but repelled. It appears that rods may be prepared for distinguishing the white metals, by boring with a gimblet a hole in the top of the rod, and putting therein a mixture, *in powder*, of coal, bones, iron, lead, tin, and copper. If

the red or yellow metals are to be distinguished, the copper filings are to be left out.

Now we arrive at Pryce's directions for using the rod. "The rod being guarded against all subjects except that which you want to discover, —as tin and copper, for example—walk steadily and slowly on with it; and a person that hath been accustomed to carry it, will meet with a single repulsion and attraction every three, four, or five yards, *which must not be heeded*—it being only from the water that is between every bed of Killas, grouan, or other strata. When the holder approaches a lode so near as its semi-diameter, the rod feels loose in the hands, and is very sensibly repelled towards the face. If it is thrown back so far as to touch the hat, it must be brought forward to its usual elevation, when it will continue to be repelled till the foremost foot is over the edge of the lode. When this is the case, if the rod is held well, there will first be a small repulsion towards the face, but this is momentary, and the rod will be immediately drawn irresistibly down, and will continue to be so in the whole passage over the lode; but as soon as the foremost foot is beyond its limits, the attraction from the hindmost foot, which is still on the lode, or else the repulsion on the other side, or both, throw the rod back toward the face. . . . We must then turn and trace it on obliquely, or in the way of zigzag, as far as may be thought necessary. In the course of tracing a lode, all the circumstances of it, so far as they relate to its *back*, will be discovered; as, its breadth at different places,—its being squeezed together by hard strata,—its being cut off and thrown aside from its regular course by a cross gossan," &c.

All particulars respecting the use of the divining-rod for the discovery of lodes, by one who was a firm believer in the "virtues," as he calls them, of the rod, have now been given. It remains only to examine the conditions involved in the use of it. Pryce says: "A little practice by a person in earnest about it will soon give him the necessary adroitness in the use of this instrument; but it must be particularly observed that as our *animal spirits are necessary* to this process, so a man ought to hold the rod with the same indifference and inattention to, or reasoning about it, or its effects, as he holds a fishing-rod or a walking-stick; for if the mind be occupied by doubts, reasoning, or any other operation that engages the animal spirits, it will divert their powers from being exerted in this process, in which their instrumentality is absolutely necessary. From hence it is, that the rod constantly answers in the hands of peasants, women, and children, who hold it simply, without puzzling their minds with doubts or reasonings."

Certain trees, especially fruit-bearing ones, are supposed to be imbued with some influence, similar to that of a magnet, and to turn by virtue of that influence towards mineral lodes of any kind, as a magnet is attracted by a mass of iron. The advances of science have made us acquainted with two forms of this subtile force—the one the true magnetic force, which causes the compass-needle to turn to iron and two or three other metals; and the other, the dia-magnetic force, which appears to act on all bodies except iron by repelling them. The first question which arises is, therefore, Does either of these forms of force act on the divining-rod?

The hypothetical influence is usually supposed to be some form of electrical energy. We are instructed by the researches of science that currents of electricity are constantly flowing around this planet, originating at the points on which the sun's rays fall in the morning—arriving at their maximum when the sun is highest in the heavens—and gradually declining as the sun reaches the western horizon (*Faraday*). Reflection on all the conditions will show that this power must be regarded as a diffusive force, enveloping all forms of matter, and that it is thrown into undulatory motion by the solar rays, or, it may be, disturbed by any mechanical power. It has been supposed that the metalliferous veins were good conductors of electricity, and the experiments of Mr. Robert Were Fox especially have been adduced in favour of the hypothesis that mineral veins were the channels through which electricity flowed freely. But the author's experiments underground, in the Cornish mines, established the fact that no electricity could be detected in the mineral lodes—unless they were undergoing a chemical change. Strong currents of electricity could *sometimes* be detected, but never unless the mineral matter was decomposing, and the electricity measured was an exact representation of the amount of chemical change taking place. The experiments of Mr. J. A. Phillips also support this view.*

If any of the divining-rods, even the most sensitive, be placed above metals or the most active mineral lodes—the rod being most delicately balanced—not the slightest indication of any action will be detected; therefore the supposed influence is not exerted between the rod and the lode. It must be sought for in the individual who bears the rod. Mr. Pryce distinctly intimates that the ignorant, and the untrained, and the impulsive peasant women and children are the best agents to work with; therefore we may venture to infer that the power which bends the rod is from within the holder, and not from without. It is no terrestrial influence. Is it some agency interpenetrating the organised structure? All evidence is against this being possible. The mind only is the power, to the influence of which the rod answers. With a *fixed idea* that sooner or later the divining-rod is to bend in the hands of the operator, he walks over a ground supposed to contain mineral lodes. Be it remembered, that the rod is held in a most constrained position—the muscles of the arms being brought into a state of extreme tension;—and a trial will show that there is a continually increasing desire to relieve the arms by moving the rod. This is often an automatic action, of which the operator is unconscious.

Happily there are now but very few persons who will trust the uncertain, the capricious action of the divining-rod. There are a certain number of men and women who are disposed to place confidence in the assertions of the ignorant or of the wilful deceivers. We solicit the attention of such to the well-weighed words of the true philosophers—Faraday, Carpenter, and others —who regard the phenomena of the divining-rod, and of table-turning, as the result of mental influences wrongly directed.

It is very important to ascertain, with the utmost possible accuracy, the quantity of ground removed by the, in many respects rude, processes of

* Reports of the Royal Cornwall Polytechnic Society.

mining carried on in the eighteenth century. Pryce is one of our best guides in this matter; therefore, although the mechanical conditions under which mining is now carried out will form the subject of consideration in the second section of this volume, it is intended to borrow from that author some remarks which appear important up to 1778.

Pryce supposes the average produce of the county to be three hundredweight of tin in one hundred sacks of tin stuff. Allowing one sack to weigh one hundred and a quarter, then one hundred sacks will be six tons five hundredweight; consequently there must be one ton of tin produced out of forty-one tons thirteen hundredweight. The county has been found to produce annually, for some few years past, about three thousand tons of pure tin metal, which, multiplied by forty-two tons of tin stuff, as above, gives the total sum of one hund-ed and twenty-six thousand tons of tin stuff per annum.

Mr. Carew, in the time of Queen Elizabeth, says: "It is found in sundry places, but to what gain to the searchers I have not been curious to inquire, nor they hasty to reveal; for of one mine of which I took a view, the ore was shipped to be refined in Wales, either to save the cost or to conceal the profit."

Mr. Norden, at the commencement of the seventeenth century, gave much information respecting the Cornish copper mines, and in a letter to King James I.* says: "So rich are the works, especially some lately found, as by the opinion of the skilful in the mystery the like have not been found elsewhere, though the worth hath been formerly exterminated by private pryers into the secret, and covertly followed for their own gain."

Pryce, writing in 1778, says: "Notwithstanding those hints, we do not find anything material going on here as to the improvement of the copper mines, till about *eighty years since* some gentlemen of Bristol made it their business to inspect our mines more narrowly, and bought the copper ores for £2 10s. to £4 per ton. . . . This encouraged other gentlemen of Bristol, about sixty years since, to covenant with some of the principal miners in Cornwall to buy all their copper ores for a term of years at a stated low price; particularly with Mr. Beauchamp, the grandfather of the present John Beauchamp, Esq., to buy all the copper ore which should rise out of a mine, well stocked, for twenty years, at £5 per ton, and the ore of Relistian, in Gwinnear, was covenanted for at £2 10s. per ton.

"About *fifty years* back large quantities of copper ore were taken from three principal mines in this county, viz. Huel Fortune, in Ludgvan; Roskear, in Camborne; and Pool-Adit, in Illogan, the produce of which mines were sold to the few buyers at their own prices.

"The four copper companies at this time were:—

"1. The Brass Wire Company.

"2. The English Copper Company.

"3. Wayn and Company.

"4. Chambers and Company."

Pryce states that at this time the confederated companies "were interrupted by a gentleman from Wales, who visited this county, in order to

* Norden's "Survey of Cornwall."

improve his own branch of business in the same way." He then tells us "that 1,400 tons of copper ore had been lying unsold some years at Roskear and Huel Kitty, for which the confederate buyers would give only £4 5s. per ton. . . . . However, this gentleman bought the 1,400 tons of ore at the advanced price of £6 5s. per ton, which he paid for with ready money, and gained much above 30 per cent., as the writer is well informed from the most indubitable authority." Beyond this, "this new comer bought 900 tons more at Roskear, at £7 per ton, and in less than six months before he left Cornwall he purchased 3,000 tons, upon which he deservedly made very little, if at all, short of 40 per cent. profit."

The following statement, drawn up by Colonel Grant Francis,* was communicated to *The Cambrian* newspaper on the 22nd September, 1868:—

"Works were first erected upon the river of Swansea for smelting copper and lead in the year 1717.

"At *Aberavon*, by Newton and Cartwright, 1727.

"At *Penclawdd*, by John Vivian, 1800.

"At *Llanelly*, by Daniel, Nevile, and others, 1805.

"At *Laughor*, by Morris and Rees, 1809.

"At *Pembrey*, by Mason and Elkington, 1846.

"At *Bank-y-Gochus*, at Swansea, in 1719;—passed into the hands of Lockwood, Morris, and Co., 1827.

"*Thomas Coster* and partners erected a copper works at Red Brook on the Wye, in 1700. He soon made a profit of £60,000."

The system of selling copper ores by public sale to the highest bidder was introduced shortly after the above transaction. The buyers and sellers mutually agreed to "ticket" for all copper ores which should at stated periods be ready for sale. Each purchaser wrote on a ticket the sum which he was prepared to give per ton for each sample of ore offered, and this ticket was handed to the clerk of the court; and when each buyer had handed in his ticket they were read over, and the highest bidder was declared the purchaser of the copper ore. Pryce says: "According to the following accounts, which are faithfully transcribed from the copper ore buyers' book, we find the quantity sold from 1726 inclusive to the end of 1735, was 64,800 tons, at an average price of £7 15s. 10d. per ton, amounting to £473,500, which must have been yearly £47,350. From 1736 inclusive to the end of 1745, 75,520 tons of copper ore were sold at £7 8s. 6d. average price, amounting to £500,106 in the gross, £65,010 yearly. From 1746 inclusive to the end of 1755, the quantity sold was 98,790 tons, at £7 8s. the ton, amounting to £731,457, annually £73,145. From 1756 inclusive to the end of 1765, the quantum sold made 169,690 tons, at the average price of £7 6s. 6d., amounting to the sum of £1,243,045, and £124,304 yearly. Lastly, from the end of 1766 to the end of last year, 1777, 264,273 tons of copper ore were disposed of at £6 14s. 6d. per ton, amounting in all to £1,778,337, which must have returned £177,833 every year of the last ten."

We have the satisfaction of being enabled to print on next page a ticketing paper of ores sampled at Redruth on the 3rd April, 1781. That was ten years later than when the above statement was made.

* "The Smelting of Copper in the Swansea District." By Colonel Grant Francis.

Ores Sampled 3rd April, 1781, and Sold the 17th instant.

	Tons.	Hore.	Bevan.	Phillips.	Williams.	Smith.	Bennallack.	Edwards.	Ennis.	Dickenson.	Stephens.	Carkeet.	Warren.	Wilson.
		£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.	£ s. d.		£ s. d.		£ s. d.		£ s. d.	£ s. d.
United Mines	92	11 3 6	10 8 0	10 4 0	10 12 6	9 17 6	10 5 6		10 4 6		9 16 0		10 10 6	10 0 0
	77	6 10 6	6 10 0	5 18 6	6 3 6	5 14 0	6 18 0		6 7 6		5 14 6		6 16 6	5 10 0
	70	13 5 6	11 2 6	11 11 0	12 9 6	11 7 6	12 0 0		11 11 6		11 8 0		11 14 6	11 10 0
	69	13 5 6	11 2 6	11 11 0	12 9 6	11 4 6	12 0 0		11 11 6		11 8 0		11 14 6	11 0 0
	41	10 16 0	10 4 0	9 9 0	10 3 6	9 7 6	10 5 6		9 17 6		9 10 6		10 2 0	9 10 0
	34	8 7 6	7 18 6	7 15 0	7 19 6	7 6 0	7 16 0		7 16 0		7 12 6		8 2 6	7 12 0
Tresavean ..	76	7 17 0	8 8 6	7 18 6	7 8 6	7 12 0	8 4 6		8 2 0		7 15 0		8 7 6	7 12 0
	37	4 13 0	5 3 6	5 5 6	5 0 0	4 6 6	4 7 6		4 7 0		4 19 6		4 16 6	4 10 6
Poldice ..	34	4 14 0	4 11 6	4 8 0	4 9 0	4 1 0	3 19 6		4 4 6		4 14 0		4 10 6	4 0 0
	24	5 11 6	5 19 0	5 16 6	5 8 0	5 1 0	5 6 6		5 13 0		5 12 0		5 17 6	5 9 0
	21	4 5 6	5 11 6	4 15 0	4 13 6	4 7 6	3 19 6		4 18 6		4 18 6		4 16 6	4 7 6
	17	4 14 0	5 6 6	4 8 0	4 9 0	4 1 0	5 2 0		5 2 6		4 14 0		4 13 0	4 4 0
Tons ..	392	306	138	37			77				34			

Tonkin fixes the discovery of the value of copper ore in Cornwall within sixty years of the time of his writing his notes to Carew's "Survey," which appears to have been about 1739—that will be about 1679. He says: "Copper has turned to very great account in this county, and there have been very great discoveries made therein, both in the eastern and western parts." After describing the various kinds of copper ore raised, he says: "The solid ore is more frequent, and also very rich in metal. In some places, too, viz. Wheal Rose in St. Agnes, Crowan Downs, Trevascus in Winnier, &c., they meet sometimes with ore so rich as to be malleable; sometimes powdered with sparks throughout with virgin copper, and sometimes with the same in leaves." Tonkin evidently intends to speak of the pure sulphide of copper (grey copper ore). After stating that the copper-ore buyers sent their ores to Wales to be smelted, that they might hide their profits, he goes on to state that about thirty years previously—that will be about 1700—"the late John Pollard and Mr. Thomas Worth, jun., of St. Ives, and *before them* Mr. Scobell, at Pol Ruddan, in St. Austell, with whom Sir Thomas Clarke and old Mr. Vincent joined (in putting up furnaces for copper smelting), were the first to produce a piece of copper in this county, smelted and refined and brought to perfection. But these attempts failed of success, more through ill-management, roguery of the workmen, and the ill situation of the said smelting-houses, than any defect in the ore or charge of the fuel."

Tonkin then informs us that one Gideon Collier, of St. Piran-in-the-Sands, erected a house for the like purpose at Penpol, in the parish of Phillach, which on his death passed into the hands of Sir William Pendarves and Robert Corker, who were for several years successful copper-smelters. At Lenobrey, in St. Agnes, a smelting-house was put up, but for want of capital it failed. In Pryce's time there were several copper-smelting companies in Cornwall—one at Hayle, established by Mr. Sampson Swaine, which continued in action until within the last twenty years; another at Entral, in the parish of Camborne; another at Tregewe, on the Falmouth estuary, which had been first established at North Downs, near Redruth. There is good evidence to prove that the adventurers of Dolcoath at one period, probably at the time when the German Rodolph Raspe * was connected with that

* This remarkable man, Rodolph Eric Raspe, was the author of Baron Munchausen's wonderful adventures. The following notice of him will be of interest:—

"The author of the Baron's wonderful adventures is now ascertained to have been Rodolph Eric Raspe, a learned and scientific German, who died in the latter part of 1794 at Mucross, in the south of Ireland, while conducting some mining operations there. Much there was of both good and ill about poor Raspe. But yet let the truth be told. Be it known, then, that this ingenious man—who was born in Hanover, in 1737—commenced life in the service of the Landgrave of Hesse Cassel, as Professor of Archæology, Inspector of the Public Cabinet of Medals, Keeper of the National Library, and a councillor, but disgraced himself by putting some of the valuables entrusted to him in pawn, to raise money for some temporary necessities. He disappeared, and was advertised for by the police as Councillor Raspe, a man with red hair, who usually appeared in a scarlet dress embroidered with gold, but sometimes in black, blue, or grey clothes.* He was arrested at Clausthal, but escaped during the night, and made his way to England, where he chiefly resided for the remainder of his days.

"Raspe had manifested decided talents in the investigation of questions in geology and mineralogy.

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just conclusions he had arrived.

"The exact time of the flight to England is not known, but in 1776 he is found publishing in London

* "Biographie Universelle."

mine, smelted their own copper ore. On the eastern side of the present counting-house, rectangular blocks of copper slag are built into the wall, and upon inquiry I find those were found amongst the waste-heaps of the mines, and that a considerable number are still buried in this débris.

The following letter, written by Mr. Thomas Williams to Lord Uxbridge, on the 6th August, 1785—especially endeavouring to adjust the difficulties

a volume on some *German Volcanoes and their Productions*, necessarily extinct volcanoes, thus again showing his early apprehension of facts then little, if at all, understood, though now familiar. And in the ensuing year he gave forth a translation of the Baron Born's travels in Tamesvar, Transylvania, and Hungary, a mineralogical work of high reputation. In 1780 Horace Walpole speaks of him as a 'Dutch savant,' who had come over here, and who was preparing to publish two old manuscripts 'in infernal Latin,' on oil painting, which proved Walpole's own idea that the use of oil colours was known before the days of Van Eyck. 'He is poor,' says the virtuoso of Strawberry Hill; the natural sequel to which statement is another three months later, 'Poor Raspe is arrested by his tailor. I have sent him a little money,' adds Walpole, 'and he hopes to recover his liberty, but I question whether he will be able to struggle on here.'* By Walpole's patronage the book was actually published in April, 1781.

"In this year Raspe announced a design of travelling in Egypt, to collect its antiquities; but while the scheme was pending he obtained employment in certain mines in Cornwall. He was residing as storemaster at Dolcoath mine in that district when he wrote and published his 'Travels of Baron Munchausen.'† Previously to this time, his delinquency at Cassel having become known, the Royal Society erased his name from their honorary list; and he threatened in revenge to print, in the form of their 'Philosophical Transactions,' the 'Unphilosophical Transactions of the English Savans, with their Characters.' This matter seems to have blown over. And now we have to introduce our hero in a new connection with English literature. The facts are fully known to us, and there can be no harm in stating them. Be it understood, then, that Raspe paid a visit to Scotland in the summer and autumn of 1789, for the professed purpose of searching in various districts for minerals. It was announced in the 'Scot's Magazine' for October that he had discovered copper, lead, iron, cobalt, manganese, &c.; that the marble of Tiree, the iron of Glengarry, and the lead of the Breadalbane property, were all likely to turn out extremely well From Sutherland he had brought specimens of the finest clay; there was 'every symptom of coal,' and a fine vein of heavy spar had been discovered. He had now begun his survey of Caithness. From another source we learn that a white saline marble in Icolmkill had received his attention.‡ As to Caithness, here lay probably the loadstone that had brought him into Scotland—in the person of Sir John Sinclair, of Ulbster, a most benevolent gentleman, who, during a long life, was continually engaged in useful projects, chiefly designed for the public benefit, and of novel kinds. With him Raspe took up his abode for a considerable time at his spray-beaten castle on the Pentland Firth, and the members of the family still speak of their father's unfailing appreciation of the infinite intelligence and facetiousness of his visitor's conversation. Sir John had some years before discovered a small vein of yellow mundic on the moor of Skinnet, four miles from Thurso. The Cornish miner he consulted told him that the mundic itself was of no value, but a good sign of other valuable minerals not far off. In their peculiar jargon, 'White mundic was a good horseman, and always rode on a good lode.'§ Sir John now employed Raspe to examine the ground, not designing to mine it himself, but to let it to others if it should turn out favourably. For a time this investigation gave the proprietor very good hopes. Masses of a bright heavy mineral were brought to Thurso Castle as foretastes of what was coming. But in time the bubble burst, and it was fully concluded by Sir John Sinclair that the ores which appeared were all brought from Cornwall and planted in the places where they were found. Miss Catherine Sinclair has often heard her father relate the story, but never with the slightest degree of bitterness. On the contrary, both he and Lady Sinclair always said that the little loss they made on the occasion was amply compensated by the amusement which the mineralogist had given them while a guest in their house.

"It will be observed that in his mining operations in Caithness he answers to the character of Dousterswivel, in 'The Antiquary,' and there is every reason to believe that he gave Scott the idea of that character. Albeit, the Baronet of Ulbster did not prove to be so extremely imposed upon as Sir Arthur Wardour was."‖

In the Library of the Museum of Practical Geology are the following works by Rodolph Eric Raspe:—

1. "Specimen Historiæ Naturalis Globi Terraquei præcipue de novis e Mari natis Insulis." 8vo. Amster et Leipsiæ, 1762.

2. "Beytrag zur allerältesten und natürlichen Historie von Hessen; oder Beschreibung des Habichwaldes und verschiedner andern Niederhessischen alten volcane in der Nachbarschaft von Cassel." 8vo. Cassel, 1774.

3. "An Account of some German Volcanoes and their Productions, with a new Hypothesis of the Prismatic Basalts." 8vo. London, 1776.

4. "A Descriptive Catalogue of a General Collection of Ancient and Modern Engraved Gems cast in Coloured Pastes," &c. 2 vols. 4to. London, 1791.

Also translations by Raspe of "Born's Travels through the Banat of Tamesvar, Transylvania, and Hungary." 1770. "Born's New Process of Amalgamation of Gold and Silver Ores and other Metallic Mixtures." 4to. London, 1790. "Ferber's Mineralogical History of Bohemia." 8vo. London, 1777.

* See Index to Walpole's Correspondence. † "Gentleman's Magazine," November, 1856.
‡ Walker's "Econ. Hist. of Hebrides," ii. 319. § "Statistical Account of Scotland," xx. 538.
‖ See Chambers's "Book of Days."

which had arisen from the large production of the Anglesea mines—will be of interest in the history of the copper trade :—

"LONDON, *August 6th*, 1785.

"MY LORD,

"I have been so hurried I cou'd not until now sit down to give you that state of the Cornish business which I wished to do.

"The real state of the Cornish and Anglesey Mines for the last 7 years has been this :—

"The former in the year 1778 produced of ore 24,536 Tons. In 1784, 37,288. In all the 7 years 209,713, which make nearly 30,000 Tons p. Ann., yielding about 3,750 Tons of Copper each year.

"The Tonage of the Anglesey Ores as raised was not much inferior in the same time, but being in that state of a very low produce the Quantities were reduced to one third of their original Tonage or thereabouts when sent to be smelted, and according to the best calculation I can make, the Copper produced from thence, 7 years ago (I mean both Mines) did not exceed 1,200 Tons at most. They produced this last year, I believe, about 2,300 Tons of Copper, and Cornwall produced about 4,700 Tons of Copper.

"Through Oppositions and Competitions at Market these properties were sold full 20 p. cent. under their value, to the very great injury of all persons interested therein.

"The Cornish Ores were sold to 11 different Copper Companies to be by them smelted and brought to Market in the metal. Those Companies sometimes combined together to run down the value of the Anglesey Copper. At others, they differed amongst themselves, yet always agreed in beating down the price of the Ores in Cornwall, and buying cheap there, they were enabled to sell the Metal at a low price, and we were obliged to do the same, or be beat out of all the Markets.

"I remonstrated on this to the Cornish Miners 4 years ago, and urged them to smelt their own ores and bring their metal to Market with us—their Interest and ours being exactly the same. They acknowledged the expedience of such a measure, but declared themselves unequal to the undertaking, for want of money, and tamely suffered the impositions until about 2 months ago, when they were roused to a due sense of them. Resolved to smelt their own Ores and applied to us to come to terms with 'em in the sale of our Metals at the same price and in reasonable proportions according to the produce of each Country whenever the Quantities should render such a regulation necessary to prevent the price from falling by means of a glut at Market. While we can get sales at a fair price, each to make the most of their property without any regard to proportions or Quantities—yet to guard against the Fall of prices through over Quantities at Market it was thought expedient on such an event to have certain specific Terms to resort to.

"The substance of the agreement proposed to be entered into betwixt the Cornish and Anglesey Miners, is as follows :—

"1st. That all the Ores of both Countries be smelted by the Owners or Lessees, and the Metal sent to one general warehouse in London, Liverpool, Bristol, and Birmingham, to be from thence sold, &c. The two parties not to be connected in any sort of partnership, or have any accounts with each

other unless in borrowing metal from each other as their exigencies may require—and though the different properties are under one roof they are to be in different apartments. No mixture of property to take place on any account—but each party to put their property under the care of their own separate Agents.

"2nd. To prevent jealousies or suspicions, the Books of both parties to be subject to the inspection of a Committee of 5 merchants to be appointed to govern and direct the trade for the mutual benefit of each party, whenever any differences arise amongst themselves.

"3rd. That to avoid the necessity for a meeting of the Committee but upon Extraordinary occasions, an Agent for both parties shall be appointed to direct the general course of the Trade—but if either party be dissatisfied with his conduct, Appeal to be made to the Committee, whose determination shall be final.

"These are the outlines of the Connection, but subject to such other regulations as may from time to time be thought necessary for the general advantage of the trade. There are numberless minutiæ of this great Concern necessary for your Lordship's Information, but I must beg leave to defer them till I have the honor of waiting upon you at Beau-Desert, which will be ere long. In the meantime I only beg you may rest assured this Cornish connection cannot do any Injury to the Anglesey Miners, but may afford them very great advantages.

"I am, my Lord, with all due respect,

"Your Lordship's most obliged and faithful Servant,

"T. WILLIAMS."

On the 20th of April, 1799, Mr. Thomas Williams, M.P., gave evidence before "The Committee appointed to inquire into the state of the Copper Mines and Copper Trade of the United Kingdom," to the following effect: "It was not until the end of the last century that copper ore was first discovered in Britain, and that was in working the tin mines of Cornwall, which had been wrought time immemorial." (This witness evidently knew nothing of the discovery of copper by the Romans.)

"Soon after that discovery, viz. in 1691, a charter was granted to Sir Joseph Herne and other merchants of London, who were thereby incorporated as a company for the purposes of refining and purifying copper ores under the firm and title of 'The Governor and Company of Copper Miners in England,' now commonly called 'The English Copper Company.' In 1694 a copper coinage of halfpence and farthings took place, and Government paid at the rate of 18d. a pound for the copper, which *was of Swedish production*. In 1717 a further coinage took place to the amount of 700 tons of *English copper*, for which the Government paid at the rate of 15¾d. per lb., or £147 per ton. In 1702 the first brass work was erected near Bristol, which has continued to this time (1799).

"For the first twenty or thirty years of the present century, and always before, most of the copper and brass utensils for the culinary and other purposes of this country were imported from Hamburg and Holland, procured from the manufactures immemorially established at Nuremberg and various

other parts of Germany. Even brass pans for the purposes of the dairies of our county could not be procured but of German make. So late as 1745, 1746, and 1750, copper teakettles, saucepans, and pots of all sizes were imported here in large quantities from Hamburg and Holland."

About this period the custom of setting or leasing a mine on tribute came into use. Some able miner takes the mine of the adventurers for a determined time, that is, for half a year, a whole year, nay, even for seven years, as was the case at Bullen Garden, and the means of her discovery. Pryce thus describes the rules by which this custom was regulated:—

"If it is a tin mine, he articles first to pay the lord, or the lords and bounders, if any, their shares or doles, free of all cost, in the stone made ready for the stamping-mill. This must be such a proportion of all tin stuff as shall be raised during the limited time. Of the remainder he pays the adventurers one moiety, or one-quarter part, according to the agreement, it being more or less in proportion to the richness of a mine. For example, in a tin mine not bounded, the lord grants for, perhaps, one-seventh. Now the tin stuff, when it is properly sized to stones not larger than a man's fist, is divided into seven doles or piles. The lord's agent, steward, or toller, casts lots upon these doles by written tickets—six marked A and one L, and which of them falls to his lot L, on that dole he puts the turf, and upon the turf a stone. Three and a half of the six A doles remaining may belong to the tributor, and the other two and a half to the adventurers, which also is transacted by dividing and casting lots as before. Where a tin mine is in *wastrel* and bounded, the manner of dividing and casting lots is more complex.

"In most tin bounds the lord's part is one-fifteenth of the whole, and the bounder's part is one-twelfth, commonly only one-tenth of the remainder. For instance, the tin stuff is divided into fifteen doles, one of which is marked by the lord's agent, as above, after the lots are cast. Then fourteen doles remain, two of which are equally subdivided and carried to the other twelve. One of these, by lot as before, belongs to the bounders, and that very likely must be subdivided again and again, it being for the most part the property of several persons.

"Of the eleven doles to be divided among the adventurers and the tributor according to the article of their agreement, the adventurers shall have three doles and one-quarter of a dole, and the tributor seven doles and three-quarters. They then cast eleven lots, viz. three marked A, and seven marked T, and one blank, and where the blank falls that dole is redivided into four parts, and lots are recast upon it; one A the adventurer's part, and the T the tributor's. This, however, is not all. The adventurer's three doles and a quarter are again divided into eighths, sixteenths, thirty-seconds, and sixty-fourths, and even much smaller fractions, that each may know and carry away his own.

"The tributor, again, may have several persons concerned with him, who redivide their seven doles and three-quarters in like manner; and thus are these fractional complicated divisions, which at first sight would puzzle the most expert arithmetician, effected by our illiterate tinners upon the simplest plan, and with the utmost dexterity, dispatch, and accuracy.

"The setting of a copper mine upon tribute has this difference. The

tributor is at the sole expense of digging, raising, and dressing all the ore that can be made merchantable; and the proceeds of sales are received by the adventurers, who pay the lord his one-seventh, one-eighth, or one-tenth part, whichever it is, in money. If it is one-eighth, that is two shillings and sixpence out of every twenty shillings, of the remaining seventeen shillings and sixpence the adventurers may have eight shillings, and account to the tributor for the residue, which is nine shillings and sixpence. And thus it is said 'Petherick Kernick of Hantergantick, Abednego Baraguanath of Towednack, Dungie Crowgie of Carnalizzy, and Degory Tripeoney of Gumford, have jointly taken a copper mine upon tribute of nine and sixpence in the pound,' &c.

"It has always been the case in large mines to set several parts of them in small portions of ground called pitches. A tribute-pitch consists of a few fathoms in length on the course of the lode. Two pitches may meet half-way between two shafts, and draw their ore to that shaft with which either of them is connected. If a pitch is high up in the mine at a shallow level, it is called a 'pitch upon the back;' but if lower down, in, or joining with the bottoms, it is called a 'bottom pitch.' The time they contract for is generally four months, and to work the pitch at all working times in a regular manner with a certain number of men. The tributor is obliged to work one month, or forfeit to the owner twenty shillings for every man he is obliged to employ: in lieu thereof, if he does not choose to continue at the month's end, he declines the occupation of his pitch, and forfeits to the adventurers all the ore which shall be broken. A tribute-taker, as well as every other man in a *bal*, obliges himself and partners to lend a hand gratis at the capstan whenever required, upon the penalty of two shillings and sixpence for each person respectively who refuses his assistance. The takers of tribute-pitches in a copper mine are likewise obliged to mix their ores with those of other pitches, or with the owner's ores, and to sample the same according to the will and discretion of the captains, else the parcels of ore would be very small where there may be twenty pitches upon tribute in one mine. Before the parcels are mixed together they take from each a fair, honest sample, and mark them A, B, and so on. These are used as checks upon the whole assay."

This question will be more fully treated of in the next section of this volume. It will be instructive, however, to give the custom in Pryce's time.

In a mixed-parcel of fifty tons, A may have twenty of £15 value per ton, B may have twenty-five of £14 10s., and C may have five of £16 per ton, according to the private samples, yet the gross fifty tons may sell for £15 5s. per ton. Nevertheless, the amounts must be divided among the tributors according to the selling price, subject to a regulation for the private samples; that is, the excess or diminution, for what it sells, must be proportioned by the produce of the private samples; for if fifty tons sell at £15 5s., the amount is equal to £762 10s. Pursuant to the above private samples:—

		£	s.	d.		£	s.	d.	
A's	20 tons at	15	0	0	=	300	0	0	
B's	25 ,,	14	10	0	=	362	10	0	
C's	5 ,,	16	0	0	=	80	0	0	
		The amount £	.			742	10	0	
			which is			20	0	0	short by private samples.

This is called £20 increase by £762 10 0 which it sold for.

Now the method of proportioning this £20 increase is done by the Ru of Three direct. Thus:—

£ s.	£ s.		£ s. d.	
If 742 10	300 0	A	8 1 7½	incre
If 742 10	362 10	B	9 15 4	,,
If 742 10	[illegible]	[illegible]	[illegible]	,,
	£742 10 0	add	£20 0 0	Amount, £762 [illegible]

Here it is evident that if the adventurers were to account to the tributors at the private prices, they would deprive them of twenty pounds of which they ought to have their respective proportions, it being the absolute value for which the commodity was sold. Also, by mixing these three parcels, they have altogether brought a better price by twenty pounds than if they had been sold separately. We further illustrate this matter by entry of an account of ores sold and proportioned to the lords, adventurers, and tributors:—

DOLCOATH COPPER ORES WEIGHED TO 24TH MARCH, 1777.

Quantity tons cwts qrs	Price per ton £	[illegible]	Amount £ s d	Lord's part, 1/7th £ s d	Adventurer's £ s
21 10 2	10	Cornish Copper Co.	215 0 0	30 14 3	184 5

TRIBUTOR'S ACCOUNT OF THE ABOVE ORE

	Quantity tons cwts qrs	Price £ s d	Amount £ s d	Increase £ s d	Amount £ s d	Tributor's part	Tributor's share £ s d
A	10 10 [illegible]	11 0 0	115 10 0	3 6 4	11[illegible] 1	[illegible] om 20s.	20 14 1
B	11 0 [illegible]	[illegible]	93 10 0	2 13 8	96 [illegible]		
	21 1	Sold at £10 per ton £215.					

The lord's one-seventh	£30 14 3
The tributor's one seventh	77 15
The adventurer's net part	106 9 10

The following extract from the Dolcoath Cost-Book for October, 1783 cannot but be of interest, as showing the actual payments received, just a century since, by the managers and the men:—

Richard Trevithick	one month, 40s					
John Vivian	ditto	40s				
Charles Vivian	ditto	40s				
And three others at the same pay						
			stems	spals	doc	
James Vivian	one month, 42s		12s	—	2d	2 13 10
Robert Reed	ditto	[illegible]			2d.	2 4 10
And two others						
Frs. Vivian		[illegible]			2d	
Four others at the same						
10 others at			—		2d	2 4 10
9 others at	ditto	30s.	6s		2d	2 0 10
6 others at	ditto	35s.	1s		2d.	1 10 10
3 others at	ditto	28s.	7s.			
33 others	[illegible]		&c.			

The month's cost being	£1769
Ditto for last month	[illegible]

It has been suggested that probably the managers made a considerable profit by supplying the mine with materials, and in the case of Trevithick we know that he received extra pay for his engineering works.

The mines of Cornwall had become so deep that the appliances which had been in use were no longer sufficient for the work they were required to do—

water-wheels working pumps, the rag-and-chain pumps, and horse whims drawing buckets of water to the surface, were no longer sufficient for the purposes of the miner. The water flowed into their lower levels quicker than any of their machines could withdraw it, consequently important mines were abandoned, or they were threatened with suspension until some means could be found to raise the water more rapidly than any machines then in use could draw it.

It is a tradition that Captain Thomas Savery was the first to place a steam-engine in a Cornish mine. It is said—I have not been able to learn if the authority is reliable—that it was at a mine in Breage—Mr. J. Carne suggests Wheal Vor—at which the experiment was tried. A short notice of this engine and of its ingenious constructor is therefore required.

"At the request of some of your members at the weekly meeting, at Gresham College, June 14, 1699, I had the honour to work a small model of my engine before you, and you were pleased to approve of it." Such is the introductory address to the Royal Society of a little book called "The Miner's Friend; or, an Engine to raise water by fire, described, and the manner of fixing it in mines; with an account of the several other uses it is applicable unto, and an answer to the objections made against it. By Thomas Savery, gentleman, inventor of the steam-engine. (*Printed for S. Crouch, at the corner of Pope's Head Alley, in Cornhill*, 1702.) Reprinted in 1827."

It is usually said that about 1702 Savery introduced his engine. This date appears to have been adopted from the little book quoted above, from which the foregoing quotation was made. I am, however, disposed to think Savery did not introduce his engine into any mine until a year or two later. That he had been in Cornwall, examining the methods employed for drawing the mines, is evident from the following: "I have known in Cornwall a work with three lifts of about 18 feet each, lift and carry a 3¼ inch bore, that cost forty-two shillings a day. . . . . I dare undertake that my engine shall raise you as much water for eightpence, as will cost you a shilling to raise the like with your old engines in coal pits" (*Miner's Friend*).

Savery's boiler was of cast iron. He appears, from his own description, to have used two boilers. He says: "The first thing is to fix the engine in a good double furnace, so contrived that the flame of your fire may circulate round and encompass your *two* boilers to the best advantage." A vacuum was formed in a receiver by admitting steam to drive out the air, and then condensing the steam by pouring cold water on the outer surface of the receiver, which caused the water in the shaft to rise by the weight of the atmosphere into the void in the receiver. A valve prevented its return, while another valve opened a passage to the up-cast pipe from the receiver towards the surface of the mine; a supply of steam again passed from the boiler to the receiver, forcing the contained water upwards through the pipes. All the principles of the modern steam-engine were involved in this simple machine of Savery's.

Savery's engine, requiring to be fixed at the bottom of the shaft, or within 30 feet of the level of the water to be raised, never came into general use. Newcomen, with his atmospheric engine, was treading close on the heels of Savery.

In 1705 Newcomen, of Dartmouth, invented the means of giving motion to a beam by using a cylinder and piston, which was a great advance. The steam pressure in his boiler was above the pressure of the air, and sufficient to drive the air out of the cylinder and produce a vacuum. This was really an "atmospheric engine," its power being the weight of the atmosphere pressing on a piston moving in a cylinder from which the air had been driven out.

In 1712 an engine called by his name was erected at Griff, in Warwickshire, which raised a load equal to 10 lbs. or 11 lbs. on each square inch of the piston. The first steam cylinder was 23 inches in diameter.

In 1720 he put up an engine at Ludgvan-lez, in Cornwall, with a cylinder of 47 inches in diameter, working fifteen strokes a minute.

Many similar engines appear to have been erected by this self-taught engineer, and his inventive genius was constantly introducing improvements.

In 1746 a Newcomen engine was put up at Pool mine, now North Wheal Crofty, which is described by Dr. Borlase,* who says: "The engine is now well known to the learned; but as their books do not reach everywhere, and this machine is especially serviceable for the working of deep mines, and of great advantage to the public revenue, a general explanation, &c., is proper." For this explanation our readers are referred to the numerous works which have been published on the steam-engine.

In 1756 several of those engines were at work. A dozen at least are named. One of these was at the Herland mine, having a cylinder of 70 inches diameter. The objection to this engine was the cost of coal. To lessen this, several methods were suggested for increasing the elasticity of the steam and reducing the size of the boiler. Strange boilers of granite were then in use, having some internal fireplace, which was probably a system of copper tubes.

Richard Trevithick, senior, was in 1765 the manager of Dolcoath mine, where at that time there were two atmospheric engines. The adventurers purchased the "Old Carloose" engine, and the elder Trevithick was employed to re-erect it. We learn that "the greatest improvement, however, was Trevithick's new semicircular boiler top, which, at a cost of £93 8s. 9d., took the place of the original flat top, weighted down by granite slabs. . . . Richard Trevithick, sen., removed the objectionable flat top; every part was made circular, giving uniform and greater strength. The increased pressure of steam in the stronger boiler, by only a pound or two on the inch, materially increased the effective force of the engine. When re-erected, this Carloose engine cost £2,040.

Trevithick senior's account-books, commencing in 1765, prove the use, ten years before the erection of his engine, of two steam-engines in the Dolcoath mine. The "Bullen Garden Fire Engine," and the "Litta Engine," and many others were then at work in other mines, for Borlase said, in 1746: "There are several other very considerable mines now worked by the fire engine in Cornwall. Huel-rith in Godolphin Hill, Herland, Bullan Garden, Dolcoath, The Pool, Bosprowal, Huel-Rose, and some others." †

* "Natural History of Cornwall." 1758.
† "The Life of Richard Trevithick, with an Account of his Inventions." By Francis Trevithick. 1872.

In 1770, Richard Trevithick, senior, obtained from Sir Francis Basset, a grant of the mine sett of Roskear, then commonly known as Wheal Chance, upon which he appears to have erected an engine of his own construction. Trevithick's account-books, commencing January, 1777, contain a list of sixty-four Cornish copper mines then at work, most of those mines having steam pumping-engines. We learn also the interesting fact that the Cornish ticketings at that time indicate a yearly produce of copper ore of about 24,000 tons, valued at £156,000.

In the history of mechanical art, an eminent professor says two modes of progress may be distinguished—the *empirical* and the *scientific*. Not the *practical* and the *theoretic*, for that distinction is fallacious: *all real progress in mechanical art, whether theoretical or not, must be practical.* Up to the time of Smeaton all progress had to be *empirical*. In 1777 Watt erected his first engine in Cornwall. He then met the Hornblowers, who came from Staffordshire, and who had been erecting engines for fifty years; and Bonze, who had five engines at work with cylinders of 60 to 70 inches diameter. Watt's advance was directly the result of *scientific inquiry*. In 1763 and 1764 Watt was employed, under the direction of Professor Robison,* in repairing a small model of Newcomen's engine which belonged to the University of Glasgow. He detected various defects in that machine, and ascertained by *experiment* the causes. From the first Watt went experimentally to work, the results of his labours being shown in the specification of his patent in 1769. The expense of carrying out Watt's invention was at first defrayed by Dr. John Roebuck, the original projector of the Carron Iron Works. On his retirement from this enterprise Mr. Matthew Boulton, of Birmingham, joined Watt, and furnished all that was necessary to render the genius of Watt practically available. In 1775 Smeaton supplied the Chacewater mine with an atmospheric engine. In 1776 the first Watt engine was built at Soho, and in 1777 he went into Cornwall, and erected an engine at Wheal Busy, near Chacewater, and another at Ting Tang, near Redruth. Hornblower and Bonze, Watt tells us, had been actively supplying the mines with various forms of the atmospheric engine. In 1782 Watt patented an *expansive engine*, applicable to both double and single engines.

The following letter from James Watt to his partner will show the condition of the Cornish mines at that time:—

"Chacewater Company sunk £50,000 and upwards in setting that mine to work; and whether they have recovered it all yet seems uncertain, although the mine has been tolerably prosperous.

"Wheal Virgin and Co. lost £28,000 in two months' unprosperous working. Poldice has sunk a very great sum, and is not now gaining nor saving. It has cost £35,000 to fit up, and drains Wheal Virgin in this working, and it costs above £10,000 a year to draw the water after all that can be done for them. Roskear mine has been long languishing, and does not pay costs now. At Dolcoath mine it is said they use £500 of timber a month, and a new kibble rope of above a ton weight is worn out in a fortnight. It takes fully fifteen minutes to draw a kibble of ore there, which weighs only about 3 cwt. It cost three years' work, and I believe as many

* "Narrative of Mr. Watt's Invention of the improved Engine." By Professor Robison. 1796.

thousand pounds, to sink a new shaft in that mine, and every fathom of an engine shaft that is sunk under the engine costs from £50 to £100.

"United mines have been at death's door, and are still in a tottering state. Wheal Union adventurers, after working more than three years, were glad to sit down with a loss of £7,000 or £8,000. *If we had not furnished them with more effectual means of drawing the water*, I believe almost all the deep mines had been abandoned before now." *

The history of the introduction of Watt's engine into Cornwall cannot be better told than by the following extracts from his own correspondence in the volume now quoted:—

"On July 25, 1776, Mr. Boulton wrote to Mr. Watt, from Soho, that he had an application for an engine from a distiller at Bristol, to raise 15,000 gallons of ale per hour 60 feet high; another for a coal mine in Wales; another for a Mr. Langdale, of Holborn, a distiller; and another for a distiller at Mile End. 'The wheel-engine is ready for trial,' he writes, except the steam-pipe; the boiler is set; and many wheels will be wanted so soon as they are ready for sale.' He says, 'If we had a hundred wheels ready made, and a hundred small engines and twenty large ones executed, we could readily dispose of them.' And on November 31, 1776, he sent to Watt to tell him that he had had a positive order for an engine for Ting Tang mine, in Cornwall; and from what he had heard from Mr. Glover, he thought they might soon expect other orders from that mining county.

"In May, 1777, Mr. Watt wrote to Mr. Boulton that 'Wilkinson is going to work in the forge way, and wants an engine to raise a stamp of 15 cwt. thirty or forty times in a minute. I have set Webb to work to try it with the little engine and a stamp hammer of 60 lbs. weight. Many of these *battering-rams* will be wanted if they answer.'

"October 30th, 1777, Mr. Roebuck wrote from Bowness to Mr. Boulton saying that he had great pleasure in hearing of the success of their engines and that they had commissions from Cornwall. In 1778 Watt was in Cornwall, superintending the erection of engines there, and his success more than equalled his expectations. He says, in writing to Dr. Black, 'We have succeeded in saving three-fourths of the fuel over the engines here, which are the best of the old kind in the island. The large engine at Chacewater mine, lately finished by us, is 63 inches diameter, has a 9-feet stroke, makes, when going out of hand under its full load, eleven strokes per minute, works a pump of 17 inches diameter and 53 fathoms deep, and moreover puts in motion a very strong connection-rod, 25 fathoms long, before it comes to the pump head; which rod, and the others which belong to three lifts of pumps, weigh above 9 tons, the *vis inertiæ* of which and its counterpoise demand a very considerable power. This engine, when going at the above rate, burns 128 bushels of Welsh coal per twenty-four hours. We have agreed to take £700 per annum for our part of the savings by this engine. The water of this mine formerly baffled two engines—one a 66 and the other a 64; but though this is the rainiest season, and the water the most plentiful below ground, we keep it very well under hitherto. But that you may know what a job it was,

* "The Origin and Progress of the Mechanical Inventions of James Watt," vol. ii. By James Patrick Muirhead, Esq., M.A. 1854.

we were three months going at the above rate in "forking," or unwatering, the mine. The whole county declared it impossible; some on account of the known great quantity of water, and others from a belief that the engine could not work the pump to that depth.' Watt, in the same letter, says that the whole county now felt confidence in the engine, and he had received orders for several others. Many abandoned mines were set to work again with Watt's engines; and at that time there were five engines actually working, and eight more in contemplation. At the same time they were making an engine to send to France; but Watt says, 'No part can or will pay us so well as Cornwall, and we have luckily come among them when they were almost at their wits' end how to go deeper with their mines.'

"The 13th of January, 1779, Mr. Watt, writing from Birmingham to Dr. Black, says that his anxiety about his engines has been very great, but now his prospects are looking much brighter, and he thinks that another campaign in Cornwall will do very great things.

"Dr. Black, on 15th March, 1780, asks Watt what he is doing at Wheal Virgin mine in Cornwall, and Watt replies in a letter, dated the 25th October, 1780, that his prospects were brilliant. 'Our income increases yearly; will have a considerable increase soon in Cornwall, and a much greater one when Wheal Virgin mine sets to work. About a year hence they are to pay £2,500 per annum, and Poldice, which will go on at the same time, £1,500. My situation hitherto has been of the most uneasy sort, and I am so habituated to disappointment, that even these splendid prospects cannot raise my spirits to par.'

"In writing from Birmingham, October 31st, 1780, Watt says: 'You have had occasion to know my sentiments from the beginning, and know that in place of this Act, which is such a grievance to them (the Cornish adventurers), I would willingly have taken £7,000 and made the invention free to all men; but neither Parliament nor anybody else would then give me that sum, though, by-the-bye, I should not have put much of it in my pocket, yet I should have been much richer than I am now. . . . . It appears by our books that Cornwall has hitherto eat up all the profits we have drawn from it, and all we have got by other places, and a good sum of our own money into the bargain.'

"July 26th, 1781, Watt went to Penryn, and swore that he had invented "certain new methods of applying the vibrating or reciprocating motion of steam or fire engines to produce a continued rotative or circular motion round an axis or centre, and thereby to give motion to the wheels of mills or other machines.' This affidavit he transmitted to Mr. Handley by post, with directions to get it passed as quickly as possible. In 1782 Watt suffered much from bad health, and he was greatly inclined to abandon Wheal Virgin and Cornwall altogether, and devote himself to the rotative machines, only he felt it would be dropping the substance to catch at the shadow. But the engines in Cornwall gave him so much trouble that he wrote, 'Peace of mind and delivery from Cornwall is my prayer.'"

About 1782 the Hornblowers caused Watt great uneasiness in Cornwall, but it was stated that their engines were not equal to Watt's, and in 1783 Watt writes: "Affairs in Cornwall go on very prosperously. It is said

Wheal Virgin will gain £3,000 per month, as it proves much richer than we expected, and the costs much less; but it will be some time before we can have any cash from it, or indeed get any considerable remittances from the county, as money is exceedingly scarce there."

In 1783 a large number of miners in Cornwall were expending considerable sums of money in working and draining the mines; and, as already stated, they were greatly indebted to the genius of Watt, for without the aid of that engineer almost all the deep mines would have been abandoned. In the same year all but one of the engines in Cornwall were altered, so were many in other parts of England.

In 1797 Mr. Watt writes: "We have got a fresh crop of engine pirates. Mr. Butt, our great opponent, has committed a great *faux pas* in Cornwall, and we have been entreated to make his engine go on our own terms, at a mine which had set us at defiance."

On the 1st March, 1802, Mr. Watt writes to Mr. Hamilton from Heathfield: "Our engine trade thrives. The profits per cent. are, however, very moderate; it is by the great capital and expensive establishment of engineers, &c., that we keep it up. Without our tools and men, very little could be done, as we have many competitors, and some of them men of abilities."

This extract sufficiently proves that at this time the firm of Boulton and Watt had overcome every difficulty. Their engines were draining all the deep mines, thus enabling the miners to penetrate to greater depths.

The elder Trevithick for many years ran a very close race with James Watt, and an unkindly feeling existed between them. The younger Trevithick, who established for himself a name as an inventor second only to that of Watt, was first employed in Stray Park mine in 1790, when he received 30s. a month, his father, as manager, obtaining 40s. a month. In 1792 he was employed by the shareholders in Tin Croft mine to examine into the duty of an engine by Watt, and of another by Hornblower. Early in the younger Trevithick's career it appears that one of Watt's pumping engines at Wheal Treasury worked badly, and at last stopped. The engineman in charge could do nothing with her, when young Trevithick offered his services, and made things right; and the father was wont to boast "that the best man in the mine could not do what his boy had done."

At the end of the eighteenth century the pit-work usually consisted of leathern buckets, with two or three pistons, such as were at that time in general use; and Lean* tells us: "They were generally in a very bad state, and it may be asserted that the engines were idle at least one-third of the time, repairing the pit-work and changing buckets." And at this time Trevithick introduced the plunger-pole instead of the common box and piston, wherever he found it practicable to do so.

Trevithick after this became extensively employed in the mines of Derbyshire and Durham. In 1798 Trevithick, by one of those moves common to master minds, converted his plunger-pole into a prime mover, in positions commanding a stream of water, through pipes from elevated ground. This was first erected by him at Prince William Henry mine,† for giving motion to

* Lean's "Historical Statement of Steam Engines in Cornwall." Published in 1839.
† Previously Wheal Chance—subsequently Roskear mine.

the pump-rods. This water-pressure engine continued to work satisfactorily for seventeen years.

Considerable discussion has arisen as to the discoveries of Arthur Woolf, and their application by Trevithick. In 1808, and not until then, Woolf was a workman under Trevithick, who paid him £30 a year, and he received at the same time £3 a week from Meux's brewery, London.

The further progress of engineering in connection with mining must be considered in the next section.

COPPER.—GENERAL STATE OF THE COPPER MINES IN CORNWALL FOR SEVEN YEARS ENDING 31ST DECEMBER, 1798, DURING WHICH TIME BETWEEN 70 AND 80 COPPER MINES WERE WORKED.

	Adventurers' Amount of Ore.			Labour.			Materials.			Total Cost.			Profit.			Loss.		
	£	s.	d.	£	s.		£	s.	d.	£	s.	d.	£	s.	d.	£	s.	d.
1792	279,331	15	10	150,824	12		91,361	6	4	251,865	19	11	27,465	15	11	—	—	—
1793	283,853	12	11	176,333	2	7	110,122	15	2	294,226	15	0				10,373	2	1
1794	293,853	10	11	179,187	15	5	111,093	19	11	294,775	19					922	8	6
1795	305,320	6	9	189,713	10	1	111,640	2	3	312,047	7					6,727	0	
1796	348,836	12	11	201,995	18	6	105,925	12	1	324,897	18		23,938	14	7			
1797	320,606	15	9	189,821	15	11	109,008	7	3	309,060	14	10	11,546	0	11			
1798	405,488	15	9	253,601	12	3	146,253	16	3	408,248	7	11				2,759	12	2
£	2,257,291	10	10	1,341,478	7	0	785,405	19	3	2,195,123	2	10	62,950	11	5	20,782	3	5

Net Profit for *Seven Years*, £42,168 8s. 0d.

The columns of labour and materials added together do not make up the total cost, because the accounts sent from some mines do not distinguish the amount of labour from materials; and therefore could be no otherwise arranged than by being carried on at once to the column of total cost.

London, 17th June, 1785.

Messrs. Vivian and Boulton, on behalf of the Copper Mine Interest of *Cornwall*, and Mr. Williams, for that of *Anglesey*, having met to consider of the best means of promoting their general and mutual interest in the copper trade, are of opinion—

That the whole of the metal to be produced by their ores should be brought to one general sale, under the direction of proper persons, and disposed of to the best advantage at one and the same price, according to the proportions produced from each country.

That warehouses for that purpose should be established in *London*, *Liverpool*, *Birmingham*, and *Bristol*, under the management of persons whose duty it shall be to consult and promote in every instance the general interest of the united stocks and trade at large.

That to this great end it will be necessary for the Cornish miners to smelt all their own ores and bring their metal into the markets, to meet the *Anglesey* metal, so that both stocks may assist each other and be disposed of together as near as may be, whereby the losses heretofore sustained by competitions at market may, in future, be effectually prevented, and the fair value of the commodity secured to the owners.

That when the Cornish miners have settled the establishments that may enable them to smelt their ores, and bring the metal to market, a meeting of the principal persons interested in the mines, both of *Cornwall* and *Anglesey*, be held for the purpose of settling all the preliminary rules and regulations of such their united trade, by which rules and regulations both parties should be bound in the strongest ties of law as well as honor.

And as it appears the mutual wish of the parties to promote this general proposition, we have every reason to hope it may be brought to a speedy and happy issue.

Witness our hands,

JOHN VIVIAN.
MATTHEW BOULTON.
THOMAS WILLIAMS.

Mr. Williams will be happy to attend the gentlemen of *Cornwall* at any meeting they may choose to fix, having notice of it in time for the journey from *Anglesey* to *Cornwall*.

The copper mines discovered in other parts of the kingdom, with the exception of the mines of Anglesea and those of Staffordshire, have no especial interest. They will therefore be treated briefly, since the most important will receive close attention in that section which is devoted to modern practical mining.

STAFFORDSHIRE AND DERBYSHIRE.—Farey, in his general view of the

agriculture and the minerals of Derbyshire (1811), gives the following list of copper mines in that county at the latter part of the eighteenth century:—

CUMBERLAND MINE	*Matlock* Bath—produced only a few specimens.
NURSERY MINE	*Hopton*. From this the specimens in the Woodwardian Collection, at Cambridge, are supposed to have been derived.
ALTOW WIN	*Ashburne*.
BONSAL	Copper ore in the vegetable soil.
HARTINGTON	"A large lump, which the late Thomas Woodhouse ploughed up on the fourth Limestone Hills."
HILL HOUSE RILETCH / MIXON MINES	*Upper Elkstone*—produced a little copper.
RIBDEN MINE	Caldon.
DALE	Warslow.
WIRE MILL	Alveton.

Dr. Plat, in his history of Staffordshire, writes: "The copper ores of this county must also be referred hither, not only as they are stones, but also as they include much sulphur, whereof there has been dug divers sorts, out of Ecton Hill, in the parish of Witton, belonging to the Right Honorable William, Earl of Devon; there is of it, too, about Beresford—near the most ingenious Mr. Cottons—and at Upper Elkston, and some think at Madeley, both in the lands of the worshipful John Offley, Esq., but none were ever thought worth digging but at Ecton Hill, where the mine was worked several years by my Lord Devon himself, Sir Richard Fleetwood, and some Dutchmen, but they had all left off before I came into the county, as not worth their while, copper coming cheaper from Sweden than they could make it here; so that the *workmen* being dispersed, I could learn little more concerning it, but that the *veins* lay from eight to fifty yards deep, but all dipt *north-easterly*; that they broke the rocks with gunpowder, and got three sorts of ore. A black sort, which was the best; second, a yellow sort, the worst; and, third, a mixed sort of both, which they smelted at Ellaston, not far off, where they had mills," &c.* Farey, in his Derbyshire,† refers also to this mine.

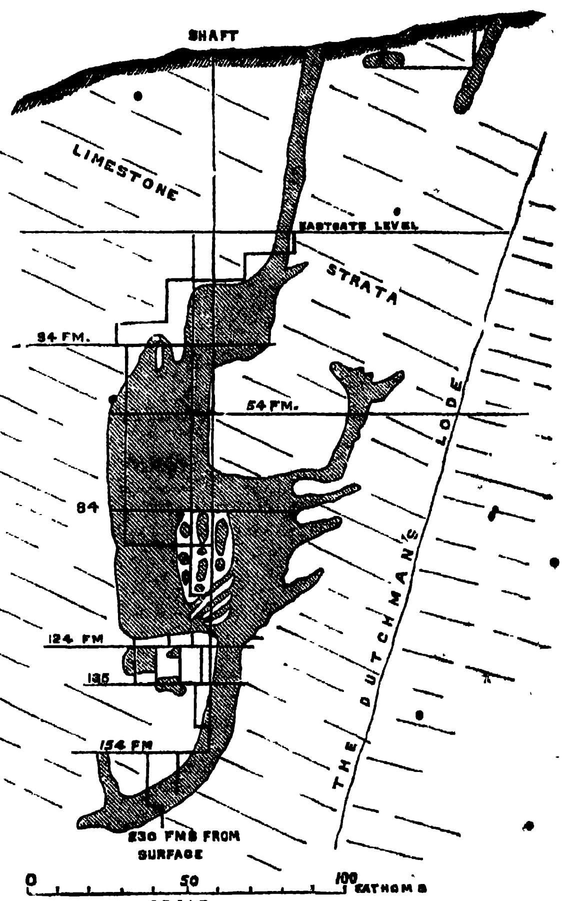

Fig. 12.—Section of Ecton Mine.

* "The Natural History of Staffordshire." By Robert Plat, LL.D. 1686.
† "General View of the Agriculture and Minerals of Derbyshire." By John Farey, sen. Mineral Surveyor. 1811.

"Near to this county (Derbyshire) is the famous Ecton mine, in Wadslow, in Staffordshire, whence most immense quantities of copper ore have been extracted before 1770. This ore was smelted at Denby, in Derbyshire, on account of the coal there being supposed to be particularly proper for the purpose, at which time works were first erected at Whiston, in Kingsley, in Staffordshire, and much enlarged in 1780, for smelting and refining the Ecton ore with coals from Hazle-cross, in Kingsley, the Duke of Devonshire, the owner of Ecton mine, having purchased the Hazle-cross estate, &c., on purpose, as I have been informed. . . . . The body of copper ore seems now (1811) nearly or quite exhausted in Ecton mine, but the thick skirts to the vein, and numerous *scrins* and small veins, or strings branching therefrom, which the miners neglected to follow when the copper ore was in such plenty, still produces considerable quantities of lead ore, which is smelted at Ecton, and about ore enough to produce a ton of copper weekly at Whiston, where about 1781 twelve tons of refined copper were produced weekly from this mine."

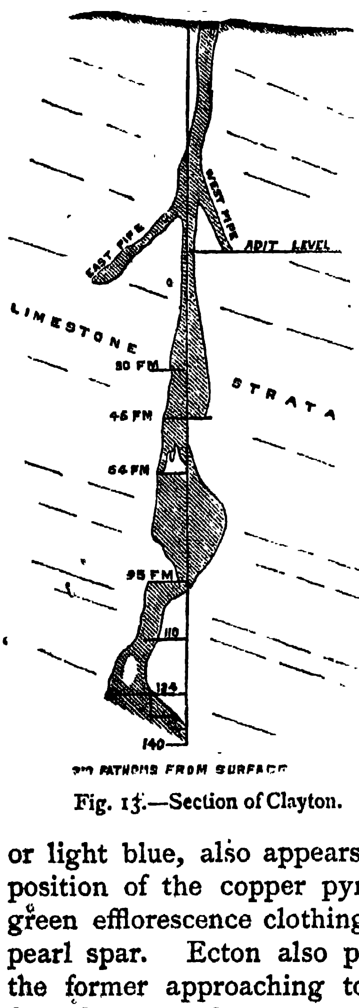

Fig. 13.—Section of Clayton.

"The Ecton copper mine,"* to quote John Mawe, "is the only one of any consequence in Derbyshire, to which, though on the edge of Staffordshire, it is generally reputed to belong. The general produce of this mine is massive rich yellow copper ore, frequently in contact with galena and blende, but specimens occur of purple, steel blue, brown, or brass yellow colours. The ore yields from forty to sixty per cent., and is sometimes vitreous and black. Sometimes, though rarely, it is crystallised in the cube and its modifications. . . . .

"The calcareous spar of Ecton is a singular modification of the rhomb, very transparent, sometimes of a rich topaz colour, and generally containing brilliant crystallised pyrites in the interior. Fluor, water-coloured, or light blue, also appears finely crystallised with galena. By the decomposition of the copper pyrites on the calcareous spar arises a beautiful green efflorescence clothing the spar, and sometimes appearing to pass into pearl spar. Ecton also produces mountain blue and mountain green, the former approaching to azure, the latter to a light verdigris colour. The fracture of these substances is earthy and uneven. They absorb moisture, and *appear* to be composed of barytes—granulated calcareous spar, and clay, with iron and green calx of copper. The famous vein of copper ore called Ecton mine lies near Hartington, being what the

* "The Mineralogy of Derbyshire, with a Description of the most interesting Mines." By John Mawe. 1802.

Germans call a *stock-work*, and the only one in the kingdom. It is situated from the surface to the bottom in a blackish-brown limestone, the strata of which are in the greatest confusion, extremely irregular, and running in all directions, as the reader may judge from the annexed plate.*

"This mine was probably worked at a very early period; it is one of the deepest in Europe, and is now (1802) worked to the depth of 220 fathoms, or 1,320 feet; during the time it produced the greatest quantity of ore the profits were immense. This work seems very different from the generality of veins; it has the appearance of large cavities or openings in the stratum filled with copper ores. There are some other mines in the neighbourhood, of little consequence. This mine was extremely productive, and at one time employed more than 1,000 people. The rich ore was in amazing large heaps, being in some places 70 yards broad, in others not more than 10 yards. It was smelted at Cheadle,† where coals are more plentiful, and the copper is greatly esteemed and much in request for large boilers, &c., being more ductile than any other." A similar formation was discovered and worked at Clayton. It will be seen from the section given (Fig. 13) that the pipe vein in Clayton had no such swelling out as was so remarkable in the Ecton mine.

CUMBERLAND AND WESTMORELAND.—Considerable copper mines existed near Caldbeck and Hesket Newmarket, in Borrowdale and in Newlands, in the neighbourhood of Keswick. Here the famous mine of Goldscalp (Goldscope) is situated, from whence, by the *old workings and other documents*, it appears that immense quantities of this mineral were formerly obtained.

"*At Newlands*, which stands among the mountains called *Derwent-Fells*, and other places near it, some rich veins of copper, with a mixture of gold and silver, were found in Mr. Camden's time by Thomas Thurland and Daniel Hochstetter, a German of Augsburg, which had, indeed, been discovered some ages before, as appears from the Close Rolls of King Henry III. n. 18, but were not wrought. So far is it from being true, that Tully hath said in his Epistles to Atticus, ''*Tis well known that there is not a grain of silver* in Britain;' nor would Cæsar have said that the Britons make use of imported copper, if he had known of the mines in this county, which afford now a plenty, not only for use but exportation. *Keswick*, also, was a place formerly noted for mines (as a certain charter given them by King Edward IV. proves), and is still inhabited by miners, as is also one of the isles in the lake adjoining by the same artificers from Germany." ‡

The following, from Robinson, gives an outline of the early history of these mines:—

"In the beginning of Queen Elizabeth's reign there was erected a copper work near the town of Keswick, the most famous at that time in England, and perhaps in Europe. The operators, managers, and miners were most of them Germans. The chief steward of the work was one Heckstetter, who, by his books of account, which are most regular and exact, and all in large imperial paper, as well as by other writings I found under his hand, appears

* Mawe gives a very rude plate. An actual section, to scale, is inserted, Fig. 12.

† William Hutchinson, F.A.S., "History of Cumberland"; "Survey of England," p. 56.

‡ The smelting operations appear to have been carried on at several places.

to have been a man of great learning as well as judgment in metals and minerals.

"The copper ore which kept these large furnaces at constant work was, for the most part, got in the veins upon Newland Mountains, the royalty whereof did then belong to the Earl of Northumberland.

"I find that some small quantities of ore were got upon Caldbeck and Cunnington (Coniston) Mountains, and brought to the great work at Keswick, being a place most convenient both for water and coal, which they had from Bolton Colliery.

"In our survey of the mountains of Newland we found eleven veins opened and wrought by the Germans, all distinguished by names given them—as Gowd-Scalp (now Gold-Scalp), Long-work, St. Thomas'-work, &c. —of all which veins the richest was that they called Gowd-Scalp. We found the vein wrought three yards wide, and twenty fathoms deep above the ground level, which is driven in a hard rock a hundred fathoms, and only with pickaxe, hammer, and wedge, the art of blasting with gunpowder being not then discovered. For securing of this rich vein no cost of the best oak-wood was spared; and for the recovering of the soles under level was placed a water-gin, and water was brought to it in troughs of wood upon the tops and sides of high mountains near half a mile from the vein.

"The ore at the top of the vein, which appeared by daylight, was *sulphurous*, but in sinking deeper, the vein got more moisture, and the ore improved in goodness.

"The ore got by the gin under level was so rich in silver, that Queen Elizabeth sued for it, and recovered it from the Earl of Peircy for a royal vein.

"Most of the most judicious miners and chymists in England were concerned in the trial, either as of the jury or evidence. The verdict was given for the Queen; and, as the German books give account, a hundred tun of ore was entered upon by the Queen's agents. This rich vein, and several more in the mountains of Newlands, are now laid open, and recovered by his Grace the Duke of Somerset; and, likewise, smelting-houses, furnaces, and all other conveniences, are made ready by his Grace for setting forward a great work." *

The following is from "Two Letters concerning several Copper Mines," bearing date 1684:—

"*What quantity of unwrought copper ore is left upon the place?* . . . ."

"To the first query I answer, that there is a heap of ore by Darwent, near Keswick, and I suppose nobody lays claim to it; but it is not worth anything, for being there so long, the weather has eaten out all the copper that was in it. . . . . All the ancient men that wrought at the smelting of it (copper ore) being dead; but it may be, Mr. Hextecher's book will give some account of it. That book is in Mr. Aglionby's custody at Carlisle. . . . .

"The third question is, *What thickness and goodness the vein of copper ore is reputed to be of?* In answer to which I say, it is reputed that the thickness of the vein at Gouldscope, in Newlands, was 6 feet; but for the

* Robinson's "An Essay towards a Natural History of Westmoreland and Cumberland." London: 1709.

goodness it cannot be known without comparison of divers sorts, to see which is best, and no comparison can be made in things unseen."

It appears that so long since as the reign of Queen Elizabeth mines were opened and worked on *Caldbeck Fells*, though the ore was said to have been carried to the great work at Keswick, to be melted. The proverb shows the estimation in which these mines were held in the sixteenth century:—

Caldbeck Fells
Are worth all England else.

No works of any account have ever been continued either here or at Newlands, although an Earl of Northumberland appears to have in a very spirited manner made sundry trials.

About 1794, William Rowe, Esq., of Liverpool, is said to have discovered, on the south side of the High Pike, a rich vein of lead ore, which, at about three feet below the surface, runs for at least a mile in length, eighteen inches thick, and even seems to increase. Smelting works were erected, but the mines were soon after abandoned.

On October 3rd, 1794, a correspondent informed Wm. Hutchinson* "that a large copper vein had been discovered upon the north side of Carrock Mountain (trials had formerly been made in several places). It is five feet wide, and the copper worth £30 to £40 per ton. It was supposed two workmen got 80lb. one afternoon. The lessee was the above William Rowe." The editor of the county history, however, says, "We have since heard that this vein has not turned out so well as was expected."

WALES.—Sir Andrew C. Ramsay† thus describes the Turf copper mine. "It was in this country, more than half a mile west of Dol-y-frwynog, that the once famous Turf copper mine was situated in the heart of the *talcose schist*, which almost everywhere contains much iron pyrites in small crystals, scattered through the rock, together with specks of yellow sulphide of copper. Very small veins of this ore also intersect the mass. A peat bog occupied the greater part of the bottom of the valley. The turf was pared off the surface and burnt in kilns, and being partly saturated with some compound of copper, a large residue of valuable copper was left in the ashes. Many thousand pounds' worth were thus extracted. The neighbouring hills were afterwards burrowed in all directions in search of the great lode or bunch, from whence the copper was supposed by sanguine adventurers to have been carried in solution to the peat. It was never found, and probably does not exist; the water, that percolated through the rocks and rose in springs, having more probably carried the copper, in the form of a sulphate, from those minute quantities of the sulphide that are more or less diffused through the mass of the hill that overlooks the Turf Copper Mine, in the peat moss of which the copper was diffusedly deposited.

"A little copper pyrites has been occasionally worked in it (purple hard grits), near Llyn Peris," near the Pass of Llanberis.

"There are four quartz lodes bearing a little copper in a mass of trap that lies west of the road between the third milestone and Tan-y-groes.

* Author of "The History of the County of Cumberland."

† "The Geology of North Wales." By A. C. Ramsay, LL.D., F.R.S., &c. &c. ("Memoirs of the Geological Survey of Great Britain." Second edition, 1881.)

Three near Tan-y-ralt, once known as the Turian lodes, ran north and south; and the other, at Cae Mawr, strikes east and west. All of these, many years ago, were worked for copper without much success. On the opposite side of the Mawddach at Glasdir-leaf, there is a copper mine, which has been opened since the Geological Map was made. It was tolerably successful, and is still worked a little. A little gold is found with the copper in this lode. There are also two quartz lodes bearing lead ore a little north-east of Moel Ispri, and at least seven similar lodes yielding copper, on the hills immediately north-west of the Barmouth road, between Llanelltyd and the fourth milestone from Barmouth."

Originally the lodes of Vigra and Clogau, near Dolgelly, were worked at intervals for about eighty years, for copper.

ANGLESEA.—The copper mines of Anglesea, viz. the Parys mine, and the Mona mine, were discovered about the year 1768. The period of their greatest produce was about 1784, when they (Parys) yielded about 3,000 tons of fine copper. Mawe, in his "Mineralogy of Derbyshire," gives the following account of a visit to Anglesea, at the latter end of the eighteenth century:—

"Being now arrived in the Island of Anglesea, I was anxious to see the celebrated mine in the Mountain of Parys. The smelting works* first attracted my attention, being superior to any I had seen, and containing twenty furnaces in a very extensive building. The mine is on the top of a mountain, of blue, or perhaps *quartose shistus*, or perhaps some might call it a *quartose shistus with serpentine*, ranging from east to west, about 500 yards in length, while the breadth is about 100 yards, and the depth nearly as much. The bottom is very irregular, masses of *rider*, or vein stone interfering; while the richer copper ore runs into holes and crevices, in strange and various directions. The shistus lies in irregular strata, and is covered with a bed of gravelly heterogeneous matter, full of chert.

"Copper is got for about two shillings a ton, and is laid in heaps of five or six hundred tons, in the sides of which ovens or fires are placed, and the sulphur in the ore soon taking fire, it continues roasting for six or nine months, and is then forwarded for smelting. The produce of the mine is very poor, about seven and a half per cent. Patches appear of fine cubic mundic. On examining this immense mine, it does not appear like a vein. About 500 yards to the east, the Cornish Company have sunk a shaft of forty fathoms, but have only found small particles and strings of ore. They have also driven north and south, but have not met with any vein.

"The Parys mine is worked at considerable expense, and with the Mona mine employs about 1,200 hands."

Mr. Thomas Williams states that the Anglesea mines produced, fourteen or fifteen years ago—that is, about 1784—3,000 tons of copper a year.

SCOTLAND.—Copper has been taken from a vein in a bed of limestone in one of the Shetland Islands, where a steam-engine was erected, and the produce for a time was not inconsiderable.

Near Gatehouse, in Flech, in Kirkcudbrightshire, at the private grounds of Cally, copper ore has been worked. Captain Treweek, of the Mona mine, visited Scotland, and formed a company for the purpose of working the

* Mona Smelting Works, Amlwch.

mine. The veins were not very regular in these first trials, being disordered and split into branches.

Mr. Taylor visited the mine in August of 1820, and found it necessary to commence an adit for the purpose of draining it. They had then shipped for Swansea about forty tons of copper, estimated to be worth £15 a ton; and then about thirty tons more had been raised.*

In a contract between the King and Cornelius de Vois, in 1567, mines of copper and tin, as well as gold, silver, and lead, are granted to him.

In 1576 the duty on copper was fixed, in the contract with Paterson, "at six stone out of every hundred, counting six score to the hundred; but it was required that, should the King require copper for making artillery for his own proper use, it was to be supplied one shilling per stone cheaper than the market price in France or Flanders." †

In 1683, a letter in favour of Joächim Gonell, a German, who had a gift of a copper mine in the parish of Currie, near the Water of Leith, says, "Many attempts for finding out and working of copper mines within this kingdom having hitherto proved altogether ineffectual," it was desirable to give the applicant the gift of the mine, that others might learn to work the mine profitably.

Aithree, between Stirling and Dumblane, a copper mine "affords copper, 50 of ane, 100 of the ore, beside that of silver to the value of an £100 ster., and to the value of £200 ster. it affords of gold.

Curry Water, four miles of Edinburgh, in John Scott of Lamphoy's ground, copper ore. "I have seen the copper made of it."

King's Park, Edinburgh, "Lapis Hœmatites is found."

Elphin, beside Allen, in the Laird of Hiltown's lands, there is copper.

Largo-law, in Fife, "Copper enough."

Borthwick Hill, betwixt Hawick and Banxome, there is copper on the north-east side.

Cantyre.—"Copper ore is found in a hole there of the colour of gold," probably pyrites.

Copper is found at Elphin, near Allen, at Largo-law, in Fife, and north-east of Borthwick Hill, betwixt Hawick and Banxome.

"Copper was found at Aithree (which lyeth between Stirling and Dumblane), "affords copper, 50 of ane, 100 of the ore, besides that of silver, to the value of £100 sterling, to the value of £200 sterling it affords of gold."

Three miles eastward of Aithree, amongst the Ochills, copper was found; and four miles from Edinburgh, in John Scott of Lamphoy's ground. In Catherall's ground, four miles from Edinburgh, lead ore was found. At Braid's Craigs copper has been found.

THE IRISH MINES.—In the days of Sir John Pettus the Irish mines were in a very uncertain state, as the following quotations will tend to show:—

As for those mines within the *English Pale of Ireland*, granted to the Mines Royal Society by Queen Elizabeth: "The Irish do acknowledge that the *English Pale* is all the Countie of *Dublin*, *Kildare*, *Carlough*,

* "Notice of a Copper Mine at Cally, in Kirkcudbrightshire." By John Taylor, Esq., F.G.S. ("Transactions of the Geological Society," Second Series, vol. i. p. 164.)
† Reg. Sec. con. 1575-77.

alias *Caterlough*, in the *Province* of Leinster, and all the Province of Meth—as it is divided into three parts, viz. East Meth, West Meth, and Longford; and this circuit is called the English Pale, because those territories were always inhabited by the English."

"But when the Society shall think it useful to make a further enquirie into the latitude of their grant from the Crown, they will find *Leinster*, *Ulster*, and part of Munster also to be included; but in so much ground as is confessed by the Irish to be within the Pale, and anciently appertaining to the English, there are store of lead *mines* affording good quantitie of silver, also *copper* mines and *iron* mines, and other metals and minerals which may prove a reward to industrie, and to the further inquiries of the Society" (*Pettus*).

The Mucruss copper-mine is situated near the head of the great lake, by which, and the river Laune, a complete water communication was opened to the sea at Castlemain. A curious fact in the history of this mine deserves attention. There was found in great profusion a mineral of a granulated metallic appearance, between 1749 and 1754, as hard as stone, its colour on the surface dark blue, tending to a beautiful pink. It was not copper ore; it was thrown away as rubbish; nobody knew what it was except one workman, who recognised it to be *cobalt ore* (arseniuret of cobalt). This man managed to get away upwards of twenty tons of it as waste. Long afterwards a more candid miner, who visited the works and saw some specimens of it, told the proprietor of its value; but the deposit of it had been worked out in order to explore for copper, and it only remained for the mine-owner to ruminate on the fortune he might have made, if he had possessed a proper knowledge of his business.

The quantity of copper ore raised whilst this mine was at work averaged 200 tons a month. It was, however, very rich—the poorest ore sold for £14 per ton, and the richest for £40. The total value of the ore raised in four years, and sold at Swansea, was £80,000.*

* "The Industrial Resources of Ireland." By Robert Kane, M.D. Second edition. 1845.

CHAPTER V.

MINING FOR LEAD, SILVER, ETC., TO THE END OF THE 18TH CENTURY.

BEFORE we proceed to the consideration of lead mines and those producing gold and silver, it is desirable to allude to the MINES ROYAL already referred to.* The Mines Royal Company appear to have established themselves as smelters on the banks of the river Neath, and probably by their influence mining operations were for a time extended; but by their exacting laws they ultimately repressed the disposition to search for minerals.

Sir John Pettus, who had been then some twenty years a governor, writing in 1670, thus defines a Mines Royal:—†

"Where the oar which is digged from any mine doth not yield, according to the *Rules of Art*, so much *Gold* or *Silver* as that the value thereof doth exceed the charge of *Refining* and loss of the baser *Metal* wherein it is contained, or from whence it is extracted, then it is called *poor Oar*, or a *poor Mine*.

"On the contrary, where the oar digged from any *Mine* doth yield, according to the rules of art, so much *Gold* or *Silver* as that the value thereof exceed the charges of *Refining*, and loss of the baser *Metal* in which it is contained, and from whence it is extracted, then it is called *rich Oar*, or a *Mine Royal*; this appertaining to the King by his *Prerogative*. And herein consists the skill and honestie of the refiner, for some have made very good products from that very *Oar* from which less skilful essayers could extract nothing."

Among the "Remembrances of the Exchequer," we find a grant from the King to *John Sugg* and *Henry of Wisbich*. "Whereas we are informed that certain *mines* of lead, mixt with gold and lead oar, are found in the countie of Salop," the King wills that the Barons of the Exchequer and Treasurer may be certified of the manner of finding the said mines, and whether any hath been transported, and by whom, &c. &c.—30th October, Anno 7. 1619.

In 1683, Sir J. Pettus translated and published the "Assays of Lazarus Erckern," chief prover or assay-master of the empire of Germany, from which we glean many important particulars and dates.

After naming twenty-three English counties and twelve counties in Wales in which the "Mines Royal Society" and the "Mineral and Battery Works Society" held various mines, he continues:—

"We have government of them all both in England and Wales, and part

* See Queen Elizabeth's Letters Patent, p. 93. † Sir John Pettus's "Fodinæ Regales."

of Ireland (except the lead mines of Donegany)—in Derbyshire, and at Mendyp, in Somersetshire. Of copper, Keswick copper mine, in Cumberland, which caused a great suit between Queen Elizabeth and the Earl of Northumberland . . . . and still have the care over it; but, for want of fuel and skilful miners, it is of no use at present."

"To work for gold, the Mines Royal Society granted two leases on mines, one at Pullox Hill, in Bedfordshire, the other at Little Taunton, in Gloucestershire, but they were not eventually successful."

"Of silver we have none but intermixed with other metals, especially lead."

"We have mountains of *Lapis calaminaris*, especially in Gloucestershire, Somersetshire, and Nottinghamshire, but we let the calamine go for ballast into foreign parts in great quantity. I remember, about thirty years ago, that one Demetrius, a German, did set up a brass work in Surry."

Carew, in his "Survey of Cornwall," quotes Sir J. Pettus on calamine, and then states, as on his own authority, that calamine has been found in the lead work by the Swanpool, in the parish of Budnich.

"*Of the Antiquitie of the Mines Royal,*" Sir J. Pettus writes:—

"These works in *Wales*, and some other in *Devonshire*, *Somersetshire*, and *Cornwall*, as far as tradition can assure us, were anciently wrought by the Romans. By the *Damonii*, in Devonshire and Cornwall; by the *Belgæ*, in Somersetshire; and by the *Dimetæ*, in Cardiganshire. And Cæsar, in his Commentaries, saith, that one reason of his invading the Britons was because they assisted the *Gauls* with their treasures, with which their countrie did abound. And *Cimboline*, Prince of the *Trinobantes* (wherein Essex is included), who had lived much at Rome in Augustus his time, was seated at *Walden*, in that countie, and did (according to the Roman way) coin monie instead of rings, which might be from that mine which was afterwards discovered by Henry IV. his time in that countie (as yet unknown to the Society). However, 'tis certain there were mines which did supply former ages, and may be again used with great advantage to this present age" (*Fodinæ Regales*, p. 11, 1670).

THE SOCIETY OF MINERAL AND BATTERY WORKS.—"The Queen did also, in the seventh year of her reign, grant to *William Humphreys* and *Christopher Shute*, a German, all *mines*, *minerals*, and *subterranean treasures* (except copperice and allom) which should be found in all other parts of England (not mentioned in the former patent), or within the English pale in *Ireland*, by the name of *gold*, *silver*, *copper*, *tin*, *lead*, *quicksilver*, *cadmium*, oar, or *Lapis calaminaris*, and all manner of *ewres*, or *oars*, simple or pure, mixt or compounded, for latten, wire, or steel, &c.

"And also on the same 28th of May, in the tenth year of her reign, the Queen frames the participants into a corporation, by the name of *The Society for the Minerals and Battery Works.*

"This was also look'd upon as so considerable a matter to the Crown that *Sir Nicholas Bacon*, then Lord Keeper; the *Duke of Norfolk*; *William, Earl of Pembroke*; *Robert, Earl of Leicester*; *William, Lord Cobham*; *Sir William Cecil*, *Sir Walter Mildmay*, *Sir Henry Sydney*, *Sir Francis Jepson*, *Sir William Garrard*, with twenty-nine more considerable persons—*gentle-*

men, lawyers, citizens, and *foreigners*—were participants. And this society consisted of 36 shares, subordinate also into half and quarter parts, so that it was capable of 144 shares. And this also by a *joynt stock* did effect great things, which turned to good advantage both to the King and to the Society."

MINES ROYAL.—About the third year of Queen Elizabeth, she, by the advice of her Council, sent over for some Germans experienced in mining, and being supplied, she, the 10th of October, in the sixth year of her reign, grants the mines of eight counties, besides those in Wales, to Houghsetter, a German, whose name and family still continue in Cardiganshire, and doubtless we had much of our knowledge from their predecessors, who revived the work in Cardiganshire. They also entered upon another work of copper at Keswick, in Cumberland, being within the royalties of the Earl of Northumberland, formerly granted to him from the Crown, together with all mines, &c. Whereupon the Earl opposed Houghsetter, but the matter being brought to trial between the Queen and the Earl, it was the opinion of the judges that, notwithstanding his frank, the Queen had power to search for treasure in anyone's ground. . . . To prevent a return of similar disputes, on May 28th, in the tenth year of her reign, the Queen erects a corporation, of which *William, Earl of Pembroke*, was the first Governour, and *Robert, Earl of Leicester, James, Lord Monjoy, Sir William Cecill*, Assistants, and many other persons of qualitie joined, consisting in all of twenty-four persons and as many shares, and those shares subdividable into half and quarter parts, so that they might consist of ninety-six persons, their votes being according to the proportions they had of shares. And this society was and is entituled *The Society for the Mines Royal*, and they have the grant and care of gold, silver, copper, &c., within eight English counties and all Wales. These counties were *Yorkshire, Lancashire, Cumberland, Westmorcland, Cornwall, Devon, Gloucestershire, Worcestershire*, and in *Wales*. As the question is constantly arising, we give the definition, *On Royal Mines*, from Bainbridge.*

"According to the law of England, the only mines which are termed Royal, and which are the exclusive property of the Crown, are mines of silver and gold.† And this property is so peculiarly a branch of the royal prerogative, that it has been said, that though the King grants lands in which mines are, and all mines in them, yet Royal Mines will not pass by so general a description.‡ This prerogative is stated to have originated in the King's right of coinage, in order to supply him with materials. In 1640 the opinion of fifteen legal counsel was taken on the subject of Royal Mines, and in 1670 their opinion was generally adopted, as stated by Sir John Pettus, who gives the Rule by which a Royal Mine may be determined.

"*The way of computing this by the art of extraction :—*

	£	s.	d.
Two tun and a quarter of oar make a tun of metal at a medium rate, £3 10s. which is	7	17	6
Carriage to mills at 6s. 8d. per tun	0	15	0
Sieves, tubs, and oar bags at 2s. is	0	4	0
So that the charge of the oar deducted at the mills which makes a tun metal costs	8	17	6

* "A Practical Treatise on the Law of Mines and Minerals." By William Bainbridge, Esq. 1841.
† 2 Inst. 577.
‡ Plowden, 336.

CHARGE OF SMELTING PER TUN.

	£	s.	d.
2 doz. white coal, at 8s. per doz.	0	16	0
5 barrels of black coal at 2s. per barrel	0	10	0
Smelting wages, per tun	0	15	4
Stamping and washing slags, per tun	0	5	0
Smith's work, per tun	0	2	4
Rents and repairs of the mills, carpenter's work, carriage to the water's side, clerk's attendance at the mills, and incident charges, per tun	1	15	0
	12	0	10

CHARGE OF REFINING PER TUN.

	£	s.	d.
300 of lead wasted in refining and reducing, at 12s. per cent.	1	16	0
Refiner's wages, per tun	0	5	0
Black coal, charcoal, bone ashes, carpenter's wages and smith's work, and other incident charges	1	10	0
	3	11	0
Total charges	16	11	10

	£	s.	d.
If the said tun of metal be made either of *Goginian*, *Coomervin*, or the *Darrein* oar, the same yields in silver per tun of metal	14	0	0
One tun of lead, the waste being deducted, as aforesaid, is	12	0	0
	26	0	0
The charge in all is	16	11	10
Deducted out of £26 the clear profit of a tun of lead is	9	8	6

If the said tun of metal be made of the oar *Coomsumblock*, it yields £20 per ton in silver.

"This is to only show the manner of computing a *Mine Royal* by art; but some are of opinion that all metals do contain *gold* or *silver* in them, and that therefore all veins of metal do belong to the King" (*Fodinæ Regales*).

DEVONSHIRE AND SOMERSET.—Silver mines have been worked at Beer Ferrers (or Beerferris, as it is sometimes called), a manor in the south-west of Devonshire, of which the borough of Beer Alston (which returned two members to Parliament) is held in Beergage tenure.*

The mines at Beer Ferrers and Beer Alston (says Lysons) are remarkable for the length of time for which at different periods they have been worked, and for the quantity of silver which they contain, the silver in each ton being from 80z to 120 ozs. Polwhele, in his "Devonshire," says "that those mines which have usually been called the silver mines of Devonshire, were no other than lead mines rich with this metal, is very evident. This appears from the inscription on the silver cup presented by Queen Elizabeth to the Earl of Bath."

Lysons, in his "Magna Britannia," says: "The lead mines of this county and Cornwall are more enriched with silver than those of any other part of the kingdom. The produce of the mines at Combe Martin and Beer Alston is said to have been unusually great in the reigns of Edward I. and II., and to have much enriched the treasury of those monarchs. The Combe Martin mines were reopened in the time of Queen Elizabeth, under the

* Risdon's "Survey of Devon."

direction of Sir Bevis Bulmer, a skilful engineer, much esteemed by that Queen and her ministers. Mr. Bushell, a celebrated mineralogist of that day, and a pupil of Sir Francis Bacon, strongly recommended the reworking of the Combe Martin mines to the Long Parliament in 1659.

In the first year (1488) of Henry VII. King of England, &c. &c., Mr. Bulmer saith: "The artists and workmen made (1485) humble suit that the mynes, mineralle, and mineral stones already by them discovered within the county of Devonshire, in England, might be supplied: for the tynners of Cornwall and Devonshire had found a part thereof which was rich, holding good store of silver, as they sought only for tynn, the shodds whereof was very brittle, and of colour like unto lead, and were found in the superfices of the earth, and contained in it by assay much silver. And the said shodds have bin found in combs and vallies neare to the river side, and not in solid places, the one place called Comb Martyn, the other Beereferris, both in Devonshire, for so it is recorded in an ould parchment booke at Mr. Somerster's house at Beerferris, in Devonshire. He was Archdeacon of Cornwall and parson of Beere," &c. Money appears to have been collected at fairs and by collections in the churches "towards the discovery of his Majesty's silver mines."

"At Comb Martyn there was a fayre storehouse builded for that purpose, &c. One thousand men were employed there and at Beereferris. Implements and tools, with other necessaries and extraordinaries, were as chargeable as wages, as is recorded in that old ancient booke, &c. And those two silver mines yielded yearly into his Majesty's treasury £44,000 sterling in bullion and in leade, which lead was sold at £4 sterling the ton weight thereof. In the year of our Lord God 1587, at Comb Martyn, in Devonshire, was discovered a new silver myne by one Adrian Gilbert, gent., and John Popler, of London, a lapidary. The which, when they found it to be stubborne to melt, and could not then master it and wyn that in the great which the small assay proffered, there went a great fame thereof throughout England. Mr. Bulmer, being then a great lead-man uppon Mendipp, in Somersetshire, having intelligence thereof, had by fortune a small quantity thereof, viz. two pounds weight, brought unto him, and the gentleman which brought it said, 'Sir, if you please, you may have a sufficient part therein,' &c. Mr. Bulmer went to Comb Martyn, 'found great store of ewer,' and bargained with Gilbert and Popler for one-half of the whole mine. For the space of two years those silver mines yielded to each partner ten thousand pounds sterling. The mines continued 'reasonable good' four years together, the last two years not yielding so much by farr as the first two years; when they were at the deepe, the said mynnes yielded £1,000 per annum. And it was called Fayes Mine, and it was wrought full 32 faddomes deepe, and 32 faddomes in length. In the hinder end of Comb Martyn's work Mr. Bulmer gave away the last cake of silver which was made out of the myne. I did both melt the leade thereof, and refined the same cake of silver, which forthwith was sent up to London and there made into a cup and cover; and Mr. Bulmer gave it gratis unto the City of London, and to remain from yeare to yeare yearly for ever, unto the Right Honourable the Lord Maior of London; and one Mr. Medly, a goldsmith in Foster Lane, made the same, with

Mr. Bulmer's picture thereupon engraved, and with these verses following annexed:—

When waterworks at Brokenwharf
At first erected were,
And Bevis Bulmer, by his art,
The water 'gan to rear,
Dispersed, I in earth did lie,
From all beginning ould,
In place called Combe, where Martyn longe
Had had me in his moulde.
I did no service on the earth,
For no man sett me free,
Till Bulmer, by his arte and skill,
Did frame me thus to be." *

In 1784 and 1785 the silver produce of these mines amounted to 6,500 ozs. The Combe Martin and Beer Alston mines have long been celebrated for their argentiferous lead ores. It is stated that the produce of these mines was unusually great in the reigns of Edward I. and Edward II. In 1293, William de Wymundham accounted at the Treasury for 270 lbs. of silver raised in Devon. In 1294 it amounted to £521 10s. weight, and in 1295 to £704 3s. 1d. weight. In 1296 great profit is stated to have been derived from the Devon mines, and 360 miners were impressed out of Derbyshire and Wales to work in them. In 1360 a writ was issued, authorising certain persons to take up as many miners and workmen as should be necessary to work in the King's mines in Devon, allowing them reasonable wages, according to the custom of the country; to arrest and imprison such as should resist, till they should give security to serve the King in the said mines; and to buy and provide timber at a competent price.

Henry, Bishop of Winchester and Cardinal of England, and one of the executors of John, Duke of Bedford, who had a grant from the King of the gold and silver mines of Devon and Cornwall, rendered 26 lbs. and 2 ozs. weight of pure silver as the fifteenth part of the pure silver raised in those counties from 15th December, 21st to 16th August, 23rd of the same King's reign.

In 1813 they were again opened, and worked for four years, producing only 208 tons of ore in that time. In 1837 they were again worked, and we had an opportunity of observing that the previous mining operations presented every appearance of having formerly been very unskilfully managed. The two lodes near Beer Alston have produced large quantities of argentiferous galena, often containing from 80 to 120 ozs. of silver per ton of lead. According to Mr. Hitchings, the greatest quantity which occurred in that part of them named South Hooe mine was 140 ozs. of silver per ton.

From Wheal Betsy, near Tavistock, which was reopened in 1806, from 300 to 400 tons of lead, and from 4,000 to 5,000 ozs. of silver, were annually obtained. The produce of this mine had been previously greatly reduced. In 1876 a little lead ore was raised, and in 1877 the mine was closed.

Borlase mentions, in 1758, that lead mines had anciently and lately been worked in Cornwall, and that those most noted formerly were Penrose, Penwerty, Trevascus, and Guarnek (Garras). He states that the Penrose mines (near Helston) had been wrought for about two hundred years—that is, from about the middle of the sixteenth century, and that they had yielded tolerable profit within thirty years. The only lead mine worthy of note at work in

* The "Discoverie and Historie of the Gold Mines in Scotland." By Stephen Atkinson. Written in the year MDCXIX. Atkinson was a native of London, a refiner of gold and silver, was a "finer" in the Tower of London about 1586, and afterwards engaged in refining silver in Devonshire from lead brought from Ireland.

Borlase's time was at St. Issy, near Padstow. Pryce describes the lead ore of Garras, near Truro, to have been so argentiferous, that when wrought, about 1720, it produced 100 ozs. of silver in the ton of lead. (This mine was reopened in 1814, and continued two years in work; during that time it produced 800 tons of argentiferous lead ore, containing 13 parts in 20 of lead, the lead yielding 70 ozs. of silver per ton.) Wheal Pool, near Helston, about 1790 gave from 40 to 50 ozs. of silver per ton of lead, and works were erected for extracting the silver. The lead ore of Wheal Rose, in the same district, contained 60 ozs. of silver per ton. The lead mines which have been worked around Chiverton and in Perranzabula belong to a later period, as do also the lead mines in Menheniot and in the neighbourhood of the Tamar and the Tavy.

LEAD AND ZINC.—Over that portion of the Mendip Hills occupied by the Mountain Limestone and Dolomitic conglomerate, lead and zinc mining has been long carried on. The principal points were Tar Valley, near Churton-Mendip, Priddy, Charterhouse, Shipham, Rowborough, Winscombe, Bleadon, Worle Hill, and Bream Down. In the neighbourhood of Wrington, on Broadfield Down, both lead and zinc have been found in the Dolomitic conglomerate. It appears that the lead ores occur most abundantly in the Mountain Limestone; zinc ores—especially calamine—in the Dolomitic conglomerate. Messrs. Buckland and Conybeare express their opinion that the metalliferous deposits of the conglomerate were derived mechanically from the débris of lodes which traversed the Mountain Limestone. They state that much of the calamine has been formed stalactitically around dogtooth spar, and that it is now found in the shape of hollow-cast and pseudomorphic crystals, the calcareous matter having perished. It appears that both ores are often found in veins, but at times they occur in beds, or are disseminated through the strata. In the Mountain Limestone the ores occur almost invariably in veins, but in the conglomerate they are frequently disseminated, though occasionally found in fissure veins. Buckland and Conybeare also remark that the veins are very thin, and that the gangue is calcareous spar, occasionally mixed with heavy spar (barytes). Mr. Weaver says the veins in the Dolomitic conglomerate run in all directions; that they vary from 1 inch to 3 feet in thickness; and that their hades, or inclination, are very variable. He enumerates galena, calamine, ironstone, manganese, calcareous spar, quartz, barytes, and ochre as the minerals found in this region.

The calamine generally occurs in small particles, mixed with a gritty earth; but at Wrington, according to Mr. Pooley, a mass was discovered about ten tons in weight. In the parish of Binegar, we are told by Mr. Billingsly, a great deal of calamine was at one time discovered. It was of very good quality, and if the miners had not been stopped by the influx of water, much calamine might have been obtained. A large quantity was also raised at Mills, which was of an excellent quality. It was found in large masses, lying horizontally in the Limestone, at about four or five feet from the surface.

"An account of lead mines producing calamine, &c., at Durdham Down, near Bristol, in the County of Gloucester; with a proposal for the disposing of a small part thereof," is curious.

"A lease was granted for twenty-one years from 1712 of 2,000 acres of

the said ground to digg, trench, sink and mine in and upon the whole or any part of the same, for the having, taking up, and carrying away of *iron ore, lead ore, magganess* (manganese), and *calamie* . . . . upon paying *one shilling* out of every ton of iron ore (allowing two-and-twenty hundred to each ton), *two shillings* for every *twenty shillings'* worth of lead ore, *four shillings* for every *twenty shillings'* worth of magganess, and *two shillings* out of every *twenty shillings'* worth of *calamie* when they are sold and disposed of."

Several pits appear to have been sunk, and it is stated that "there are many £1,000 worth of oar in view;" and "the small veins already discovered are above 600, and which are found to run a tract of near a mile long," containing "the calamie, of which may be got up many thousand tons."

Much discussion has arisen over the question whether this metal, ZINC, was known to the ancients. Beckmann insists upon it that Aristotle and Strabo were acquainted with the ore of *Luna Calamine.* He contends that the *Cadmia* named by them—which was found in Cyprus, and used for the manufacture of brass—was the ore, calamine. The probability appears to be that cadmium, furnace-calamine, philosopher's wool, *Luna philosophica Pompholyx* (so called by Dioscorides), was known to the ancients as an Earth, the metal zinc being the discovery of a later day, its name occurring first in the works of Paracelsus, who died in 1541. Even then it is mentioned as a rare thing, possessing wonderful properties.

Bergmann, in his history of the discovery of the method of extracting zinc from calamine, wholly omits the mention of Dr. Isaac Lawson, of whom Pott, in his essay on zinc, speaks very respectfully, acquainting us that he really obtained some grains of that semi-metal from calamine. So that, though Henckel was the first, Lawson was probably the second person in Europe who procured metallic zinc from calamine. Whether he was the Englishman who, according to Bergmann, went to China to discover the method of doing it, is what I have not been able to learn with certainty. Our English writers who have touched on this subject speak in high terms of Lawson—I suppose from their personal knowledge of him—for they do not refer to any written account.*

Thus Dr. Pryce says: † "The late Dr. I. Lawson, observing that the flowers of *Lapis calaminaris* were the same as those of zinc, and that its effects on copper were also the same with that semi-metal, never remitted his endeavours till he found the method of separating the pure zinc from that ore." And Dr. Campbell, in his "Survey of Britain," is still more particular.‡ "The credit if not the value of calamine is very much raised since an ingenious countryman of ours discovered that it was the true *mine* of zinc. This countryman was Dr. I. Lawson, who died before he had made any advantage of his discovery." The authors of the "Supplement to Chambers's

* Pott gives several quotations from a dissertation by Dr. I. Lawson, "De Nihil," which I have never met with, and amongst others the following one: "Quamois tapis calaminaris nec sublimatione, nec cum fluxu nigro det zincum tamen similes flores, similis in igne color, similis tinctura cupri, et augmentum ponderis probabilissimum, præbent argumentum lapidem calaminarem esse mineram zinci."—*Pott,* "*De Zinco.*"

† "Mineral. Cornubiensis," p. 45.

‡ "Polit. Surv. of Brit.," vol. ii. p. 35.

Dictionary,"* published in 1753, expressly affirms that "Dr. Lawson was the first person who showed that calamine contained zinc. We have now on foot at home, a work established by the discoverer of this ore, which will probably make it very unnecessary to bring any zinc into England." To all this I shall only add one testimony more, from which it may appear that the English knew how to extract zinc from calamine before Mr. Van Swab taught the Swedes the method of doing it; though this gentleman, unless I have been misinformed, instructed the late Mr. Champion, of Bristol, either in the use of black-jack for the same purpose as calamine, or taught him some improvements in the method of obtaining zinc from its ores. The testimony occurs in a dissertation of Henckel's on zinc, published in 1737. He is there speaking of the great hopes which some persons had entertained of the possibility of obtaining zinc from calamine—hopes, he says, which had been realised in England: "Ce qu'un Anglais arrivé depuis peu de Bristol dit avoir vu réussir dans son pays."†

The manufactory, however, of zinc was not established at Bristol until about the year 1743, when Mr. Champion obtained a patent for the making it. About two hundred tons of zinc are annually made at the place where the manufactory was first set up; and about seven years ago zinc began to be made at Henham, near Bristol, by James Emerson, who had been many years manager of that branch under Mr. Champion, and his successor in the business.

"Near twenty years ago I saw the operation of procuring zinc from calamine performed at Mr. Champion's copper works near Bristol. It was then a great secret, and though it be now better known, yet I am not certain whether there are any works of the kind yet established in any other part of either England or Europe, except that before mentioned at Henham. In a circular kind of oven, like a glasshouse furnace, there were placed six pots of about four feet each in height, much resembling large oil-jars in shape. Into the bottom of each pot was inserted an iron tube, which passed through the floor of the furnace into a vessel of water. The pots were filled with a mixture of calamine, or black-jack, and charcoal, and the mouth of each was then close stopped with clay. The fire being properly applied, the metallic vapour of the calamine issued through the iron tube, there being no other place through which it could escape, and, the air being excluded, it did not take fire, but was condensed in small particles in the water, and being re-melted, was formed into ingots and sent to Birmingham under the name of zinc or spelter."‡

"Queen Elizabeth in 1565 granted by patent all the calamine in England and within the English pale in Ireland to William Humphrey, her paymaster, and one Christopher Shutz, a German, and, as the patent sets forth, a workman of great cunning, knowledge, and experience, as well in the finding of calamine as in the proper use of it for the composition of the

* Art. Calamine and Zinc.

† This observation was first published in the fourth volume of the "Acta Physico-Medica Acad. Nat. Cur.," 1737, but I have made the quotation from the edition of Henckel's works published at Paris, 1760, vol. ii. p. 414.

‡ "Chemical Essays," vol. iv. pp. 33–40. By R. Watson, D.D., F.R.S., 1786.

mixt metal called latten or brass."* Dr. Watson appears to think that the Mineral and Battery works established in 1568 were materially concerned in the metallurgy of zinc. Moses Stringer, already quoted, says that mines of *latten*, whatever, at that period, may have been meant by that word, are mentioned in the time of Henry VI. (the 15th century), who made his chaplain, John Botterright, comptroller of all his mines of gold, silver, copper, latten, lead, within the counties of Devon and Cornwall. In 1639 a proclamation was issued prohibiting the importation of brass wire, and about 1650 a German called Demetrius established a brass work in Surrey at the expense of £6,000, and employed above eight thousand men in brass works near London and Nottingham. Yet in 1670 Sir John Pettus† says the brass works were decayed and the art of making brass almost gone. In 1708 the brass makers in England presented a memorial to the House of Commons soliciting the protection of Parliament.‡ They stated "that by reason of the inexhaustible plenty of calamine," England "might become the staple of brass manufactory for itself and for foreign parts;" "that the continuing the brass works in England would occasion plenty of rough copper to be brought in, and make it the staple of copper and brass." In 1720 it was remarked by W. Wood, in his work on the state of the copper and brass manufacture, that this nation could supply itself with copper and brass of its own produce if such duties were laid on foreign copper and brass as would discourage their importation.

An ancient charter exists, of which we give a facsimile, of the date of Edward IV. (about 1480), which, in a rude attempt at plan-drawing, curiously, and still correctly, represents the "Myne deeps," as they were then called. Taking advantage of an offer made by an intelligent and scientific friend to inquire if any other copies existed of the map which is in the *Mining Record* office, I had the satisfaction of receiving an interesting letter, which I annex.

"I have seen the map of the Mendip. It is very curious, and is a counterpart of the documents you have. It is quite clean, and has been used as a sort of panel in a good house. It is on canvas with a curious sort of framing (painted wood), and is about 4 feet by 2 feet (less than 5 by 3). There is painted the "Mendip Minerys—churches above and below, and land on each side."

"The subject seems a counterpart in matter to your copies, but, I think, a difference of person; in the preamble, after speaking of making a peace and contentment,—the Prior of *Green Ore* is named,—and I do not remember that in yours. Now Green Ore is two and a half, or three miles, from this spot, and six from Wells—plain on the Mendips.

"It (the drawing) was found at Bristol at a curiosity shop, and brought over to Wells by a surgeon, thinking some person would buy it, or that a lottery could be got up to keep it in Wells. The price is £15.

"I heard that years ago at Axbridge another of these maps—supposed to belong to some other court—was sold for £60 to a gentleman, at whose

* "Opera Mineralia Explicata." By Moses Stringer, M.D. 1713.
† "Fodinæ Regales," p. 33.
‡ "Opera Mineralia."

decease, at a public sale, it fetched £30, and is bought for an institution. will get, some of these names and particulars if I can, and something c interest may come out of the affair.

"The medical man, a stranger, to me, said he had no other than loca interest in the affair, and had been a customer to the Bristol shop, and so i had been lent to him to sell here. "THOS. J. PEARSALL."

This document, though exceedingly rude, contains a considerable amoun of information. The dogs hunting signify that the "Myne deeps," as the were then called, were "a Royal Chase," and therefore preserved by th Sovereign. All the churches signify so many parishes, and to a certai extent the character of those have been preserved. The chief mines ar correctly placed, and the drawings at the side convey a fairly good idea o the mining process employed at this date. On the original the "Laws o the Myne deeps" were inscribed at the side of the map, and within th space occupied by the drawings.

THE LAWES OF YE MYNEDEEPS.

BE IT RIGHT WELL KNOWN, That this is enrolled in the King's Highnesse Exchequer by the time of Kinge Edward the Fourth of a great debate that was in the county of Somsr. Between the Lord Bonville's Tenants of Chuton and the Prior of Greene Ware. The said Prior complain'd unto King Edward of great injuries and wrongs that he had upon Myndeepe being the King's fforrest. The said King Edward comanded my Lord Short, being Chief Justice of England, to goe downe into the country of Meyndeepe and sett a concord and pease in the country upon Meyndeepe upon paine of his high Displeasure. The said Lord Shorte sate upon a place of my Lord of Bathes called the fordge upon Meyndeepe. Whereas he comand. all the commoners to appeare there, and in especiall the fowre Lords Royall of Meyndeepe. That is to say, my Lord the Bishop of Bath and Wells, my Lord Glastonbury, my Lord Bonville, Lord of Shuton, and my Lord of Richmond, with all the appearance to the numbers of tenn thousand people. A proclamation was made to anquire of all the saide company how they would be ordered. Then they all with one assent made answer and said that they would be order'd and tryed by the fowre Lords Royall. Then the fowre Lords Royall were agreed that all the commoners of Meyndeepe dwelling in their tenements, being within the said bounds of Meyndeepe, shoulde turn out their cattle att their outletts as much the sumer as they be able to keepe the winter without hounding or pounding upon whose grounde soever they went to take their course and recourse. To this the said fowre Lords did set their seales. And also weere agreed that whosoever shoulde breake any of these bounds should forfeit to the King one thousand markes and all the pleasure that doth either hound or pound.

THE OLD ANCIENT custom of the occupation of the Mynedries in and upon the Kinges Majesties fforrest of Meyndeep w'th in his Majesties county of Somer'et, being one of the fowre staples of England, which hath been verrified, used, and continued through the said fforst oft from the time whereoft man now living hath twoo memories as hereafter doth particularly ensue ys.

1. FIRST, That if any man whatsoever he be that doth intend to wentor his life to be a workman in the Myndery occupation, he must first oft. all reqire lyence of the Lord of the Soyle where he doth purpose to worke, or in his absence of his officer as Load Rove or Baylie, and in the Lord neither his Bayliffe or officer can deny him go.

2. *Item*, That after the first lycence had the workman shall never need to ask leave againe, but to be all his freewill or pitch within the saide fforrest, and to breake ground wher and in what place it shall best like him to his behoofe, and of it using himselfe justlie and trulie, &c.

3. *Item*, That every man that doth beg in his pitt or groove shall have his hact throw two wayes after the rake; and note that he that doth throw hact must stand in his pit or groove to the girdle or wast. And then no man shall or may work within the compass of his said hacks throw.

4. *Item*, That when a workman hath landed oare he may carry the same to cleansing and blowing to what Myndery he shall please for the more speedy making of the same, for that he doe trulie pay the tenth thereof to the Lord of the Soyle where it was landed.

5. *Item*, That if any Lord or his officer have once given lycence to any man to build or sett upon any hearth or washing-house to wash and cleanse and blow their oare, he who hath for once leave shall for ever keep it, sell it, or give it to whom it shall please him for that he doe truly and justly pay the lott lead which is the tenth pound that shall be blowne at the same hearth. And also ift he do keepe it tenantable as the draft doth require.

6. *Item*, That if any man of that occupation doe pick or steale any lead or lead oare to the value of viii.d. the Lord his officer may arrest all his lead and oare, house or hearth, with all his grooves and workes, and keepe them as forfeit to the owner. And shall take the person that hath so offended and bring him where his house or worke, and all his tools and instruments belonging to the same occupation be, and put him into his house or worke and sett fire in all together about him and banish him from that occupation before all the Meynders for ever.

7. *Item*, That if ever that person doe pick or steale there any more he shall be try'd by the common law, for this custom and law hath no more to doe with him.

8. *Item*, That every Lord of Soyle or Soyles ought to keep two Meyndrie Courts by the year, and to gooard twelve men or more of the same occupation for the orders of all misdemenowrs and wrongs touching the Meyndries.

9. *Item*, The Lord or Lords may make three manner of arrests (that is to say), the first is for strife between man and man for t[redacted] under the earth; the second is for his own duty for lead or oare [redacted]r he find it within the said fforrest; the third is upon ffelons [redacted] the same occupation whersoever he find it within the same hill.

10. *Item*, That if any man by the means of this dou[redacted]dangerous occupation do by misfortune take his death, as by falling [redacted]upon him, by drowning, by stifling with fire (or otherwise as in t[redacted]may have been), the workmen of the occupation are bound to f[redacted]dy out of the earth and bring him to Christian burial at their o[redacted] costs and charges although he be three score fathom under the ear[redacted]fore

"Description by Mr. J. Beaumont (Phil. Col., n. 2, p. 1) of Lead Mines And Caverns in the Mendips, from the Philosophical Transactions and Collections to the end of the Year 1700. Abridged by John Lowthorp, M.A., F.A.S. (1705.)"

On the south side of the Mendip Hills, within a mile of Wells, is a famous grotto, known by the name of Cokey Hole. This is fully described, and a strange account given of the eels found in the river flowing through the levels, and the bats which inhabit the vaulted passages, but no mineral matter is found in it; but, "before you come to the middle of this vault, you will find a bed of very fine sand, which is much sent for by artists to cast metals in."

"About five miles from this, on the south-west part of the Mendip Hills, near a place called *Cheddar*, lies another cavern." "These two caverns have no communication with mines, but we generally observe that wheresoever mines of lead ore are, there are caverns belonging to them. The most considerable of these vaults I have known on *Mendip Hills* is on the most northerly part of them, in a hill called *Lamb*, lying above the parish of Harptry. Much ore has formerly been raised on this hill; and being told, some years since, that a very great vault had been discovered there, I took six miners and went to see it." The description which follows very closely agrees with that already given.

Captain Sturmy, on the 2nd July, 1699, states "that he descended, by ropes affixed at the top of an *old lead ore pit* at Pin-Park Hole, in Gloucester, 4 fathoms almost perpendicular, and from thence 3 fathoms more obliquely, between two great rocks, where I found the mouth of this spacious place, from which a mine-man and myself lowered ourselves by ropes 25 fathoms perpendicular, into a very large place, which resembled to us the form of a horseshoe, for we stuck lighted candles all the way we went to discover what we could find remarkable." They found a river 20 *fathoms broad and* 8 *fathoms deep!*

"As we were walking by this river, 32 fathoms under ground, we discovered a great hollowness in a rock some 3 foot above us; so that I got a ladder down to us, and the mine-man went up the ladder to that place, and walked into it about 70 paces, till he lost sight of me, and from thence cheerfully called to me and told me he had found what he looked for, a *rich mine.* But his joy was presently turned into amazement, and he returned *affrighted by the sight of an evil spirit!*

"There are abundant of strange places, the flooring being a kind of white stone *enamelled with lead ore*, and the pendent rocks were glazed with salt-Peter, which distilled upon them from above, and time had petryfy'd."

Sir Robert Southwell informs us that shortly after this expedition Captain Sturmy died, implying from the effects of damps in these vaults. Captain Collins describes this cavern fully, and Mr. J. Gill affirms that, where water is in such caverns they never want air.

Mr. J. Beaumont, who has been already quoted, says, "There are in Mendips, and generally where mines are, subterraneous vaults or grottoes, whereof some which are pretty deep, and admit not air too freely, and have other conditions required, are said by our miners to be *quick*, having ore

often in them, and still lively coloured earths, &c. &c.; others admitting air two or three ways, and having in them black and moist rocks, and dry and rotten *shaly stones*—dark earths, barren sand, and the like—being said to be *dead*."

THE LAWS OF THE LEAD MINES IN DERBYSHIRE.—From the *Bundle of the Exchequer* and *the Inquisition* of the *year of the reign of King Edward I.*, 16. (1288.)

The King appoints "*Reynold of the Ley* and *William* of *Memill* to inquire by oaths of good and lawful men of your country" the liberty which the miners claim. This command was given to "our well-beloved cousin Edmond, Earl of Cornwall, at Westminster, the 28th day of April, in the year of our reign the 16th.

"By *William of Hambleton*, and at the instance ot *Hugh of Cressingham*, the day is appointed at *Ashbourne*, upon Saturday next after the Feast of the Holie Trinitie."

Twelve jurors were sworn, and the following laws were settled on, upon their oaths:—

1. "Who say, upon their oaths, that in the beginning when the miners did come to the field seeking for a mine, and finding a mine, they do come to the bailiff, which is called *burghmaster*, and did desire (if it were a new field) that they might have two meers of ground; that is to say, one for the finding hereof, and the other by the miners' fine, viz. paying a meer dish of his first oar."

2, 3, 4, settle the meer.

5. "The King shall have the thirteenth dish or measure of oar, which is called *The Lot*."

7, 8, 9, settle the rules for selling ore.

10 makes an exception of "a certain place, then called *Man Dale*, in which place all buyers of oar are prohibited to buy oar for the space of four years last past by the burghmaster."

11 settles "that the pleas or Courts of the burghmaster ought of right to be kept and holden yeerlie upon the mines from three weeks to three weeks."

The remaining clauses settle time, trespasses, and liabilities for "every bloudshed."

THE LIBERTIES AND CUSTOMS.*—The first clause settles that "a meer shall contain in length 10 wands and 7 feet, that is to say 87 feet." The miners to have their meer for ever—unless it be forfeited to the lord.

Directions are given for the working of the meer, a [redacted] rghmaster shall see that the mine be wrought duly." If he finds [redacted] neglected "he shall score on the spindle one score, and so from [redacted] k." If he finds the mine unworked for three weeks together "he [redacted] three score on the spindle and deliver it to him that will work it as [redacted] ll."

The miner is to be granted by the burghmaster a su [redacted] ce "for his

* The "Mineral Laws of Derbyshire." These laws or customs remai [redacted] ript until they were printed at London in 16mo, in 1688, under the title of the "Complete [redacted] were reprinted in 1734 in 8vo, with additions by George Steer, and again in 1772 by Willia [redacted]

lodge and for his cottage with sufficient house-boot and hay-boot, and all manner of timber for their groves."

The miners shall have for their beasts pasturing with the lord's beasts in his wastes, and "no minister of the lord's shall pin them nor distrain them."

"Also the stewards shall hold yearly on the mines at their own wills courts, and two great courts every year; and if any miner or other person be attaint for stealing of barmine, first he shall be amerced in it 5s. 4d., the which 4d. the burghmaster shall have, and if he be attaint again the miner shall be amerced 10s. 8d., the which 8d. the burghmaster shall have, and if he be attainted the third time he shall be *stricken through the right hand in the palm with a knife up to the heft into the stow, and there shall he stand till he be dead, or else cut himself loose*, and then he shall forswear the franchise of the mine."

The miner for any act of felony in the mine is to be fined £100.

"Each trespass of oathes or bloud shall be amerced 5s. 4d.," and the like.

"The miners and merchants shall have weights for their lead and measures for their oar."

"If it happen that the miners or any other be dead in the grove or elsewhere, no escheator or commoner nor no other officer of the lord shall meddle of lands, goods nor chattels of him that is slain or dead by any misfortune, but only the burghmaster of the mine."

"The lands and chattels of felons and fugitives shall be forfeited (if they have no better grace)."

"The miner and merchant shall have free entrie and issue by all the lordship to carry their mine, and carry it whither they list, without let of the lord or any of his officers; but they shall give to the King for every lord fourpence for entrie and issue by his lordship, and that is called *Cope*; and if any miner or merchant died by misadventure under the earth, or be slain by chance medly, the burghmaster shall see his bodie as coroner, and let his bodie be buried without any coroner."

"And the miners shall have for their lot and *Cope* sufficient timber for their work (without any penie giving) of the next founder within the King's lordship. Also they shall have water to wash their mine without any let for the said lot and cope." (See page 140.)

"If the lord will buy their mine for as much as any other man will give them, he shall have their mine before all other men," &c. &c.

"In witness thereof," &c. &c.

"These being the laws and customs of the mine used in the highest *Peak*, and in all other places through England and Wales; for the which to be had the wise miners sueth to our lord the King that he would confirm them by his charter under his great seal in way of charitie.

"And for his profit, forasmuch as the aforesaid miners be at all times in peril of their death, and that they have nothing in certain but that which God of his grace will send them.

"FINIS.

"WILLIAM DEBANCKE."

The following Law of the Barmot deserves a brief notice: "Cur Magna

Barmot, TENT APUD WWKSWORTH CORAM, FRANCISCO (1550); *Com. Salop 20 die Septembris Anno Regni Edward VI. &c. Tertio. Inquisitro Magna pro Domino Rege Miner infra. Wapentag prædict. per Sacramen.*"

Twenty-four jurors whose names are given say, "We do present and set down pains for the miners as followeth":—

The measures of ore were first settled.

Then they deal "*with ground unjustly wrought.*" Ore-stealers and other offenders are to be punished. Disputes as to "*trials and for grounds in variance.*"

"If there be any man that maketh title to any man's ground, contrary to right, and it be tried by the law, he that is cast, shall pay two shillings *for the twelve men's dinners*, and if he will not pay it then the burghmaster shall take so much oar of him as cometh to two shillings, *or else some other distress if he be worth so much.*"

Debts are regulated, the holding of courts arranged, the payment of lot settled, the fixing of crosses and holes to hold possession of ground, the buying and selling of ore, gauge and counterfeit dishes to be kept, and the settlement of groves and fines are finally adjusted.

Another set of laws were determined on in 1558: "*Cur Magna Barmot. Dom. Regis and Dom Reginæ Tent apud Wricksworth 3 Maii, Annis Regni, Phillippi and Mariæ. Dei Gratia Regis and Reginæ Angliæ, Hispannæ Franciæ, &c., tertio and quarto.*"

"*Inquisitro Magna pro Domino Rege & Domina pro Miner infra Wapentag prædict secund consuetud ibidem usitat per Sacramen.*"

Twenty-four jurors settled—

1. That the lord should provide able dishes.
2. No miner to dig within seven feet of any man's washing-trough.
3. No ore to be sold if the owners are not on the ground.
4. Not to dig near any man's dwelling-place.
5. No purchaser shall stop a miner from using a wash-trough.
6. Barmasters to measure poor men's ore.
7. None to deliver ore except by the King's dish.
8. Allowing twelve men's dinners at the court of barmote.
9. Every miner must be lawfully summoned.
10. *Stows*, timber, picks, &c., not to be moved.
11. Possession not held by holes and crosses above three days.
12. Wood and water allowed by the King.
13. The Barmaster shall allow the miners to make a [redacted] water.
14. Miners' privileges.

Sundry rules follow as to the owner of a new vein, [redacted]lating the measures of ore, punishment for stealing ore from any [redacted]nd several laws regulating the action of the Barmaster.

The old method of working lead mines in Derbyshire [redacted]lows:* A person having found a vein of ore, made certain crosses [redacted]ound, as a mark of temporary possession, and then went and infor[redacted]Barmaster, who attended and received a measure or dish of ore, the[redacted]uce of the

* "General View of Agriculture and Minerals of Derbyshire." By Jo[redacted] 1811.

mine, as the condition of permitting him to proceed in working his *meer*, or measure of 29 yards in length of the vein; the Barmaster at the same time taking possession of the next adjoining 14½ yards, or half meer of the vein, for the King. And if the vein seemed promising, it often happened that at the same time, or soon after, there were various applications to be admitted each to free his meer, or 29 yards in length of the rake vein in succession. It was a condition, that each person or company possessing their meer or meers in partnership, called *groove-fellows*, should immediately begin and continue to work at their mine, as in case of intermission for three successive weeks, the Barmaster was authorised to dispossess them, and give the mine to another.

As these first mines were all in the district where the Limestone has no other cover but the corn-soil, each miner went to work, and with mattocks or picks, and with hammers and iron wedges in the harder veins, loosened the ore and spar, and threw out the latter into a bank or ridge of their *vestry* or *bowse*, on each side of the vein, proceeding thus to sink and throw out vein-stuff, as deep as was practicable, when a square frame, composed of four planks of wood laid across and pinned together at the corners, on which two others were erected, with holes or notches to receive the spindles of a turn-tree or rope-barrel, for winding up the ore in small tubs. This apparatus, called a *stowse*, being erected on each meer, or mine, the sinking was further continued, and the heaps on the sides of these *open-works*, or open-casts increased until, in numerous instances, a perpendicular ditch, of the width of the vein and many yards deep, was opened, with proportionally large heaps of rubbish on each side, for many hundred yards in length, with other similar veins and heaps parallel to and crossing them at certain angles.

Great numbers of the mines thus opened proved too poor in their produce of ore to be sunk lower than men could throw out the stuff, therefore the miners abandoned them, after some progress had been made in deepening them by means of stowses.*

"As the mines which proved richer in ore increased in depth, instead of continuing to draw up the vein-stuff to the surface, the miners constructed floors or stages of wood across the mine, called *bunnings*, just above their heads, and on these threw the refuse or vestry for the whole length of the mines, which thus became covered over, except just under the stowses, or drawing apparatus, at which place they sunk six or eight feet or more lower, and after clearing some distance, began other bunnings under the former, on which the refuse was thrown as before. And as the work thus proceeded, the shaft under the stowse was either lined with timber or stone, called *ginging* it, and the vein-stuff which was drawn, being thrown on to the bunnings on each side, a regular hill was at length formed, and increased round each shaft, and is called the *mine-hillock*, or *hillock*. In process of time, as the mine increased in depth and having reached to water in the strata, the drawing of such in barrels, and the ore and vein-stuff which [illegible] not be stowed on the bunnings, so increased the labour and [illegible] many valuable mines were abandoned on that account,

* Similar [illegible] opening and working lead veins have been practised in the island of Islay, in Scotland. ([illegible] "Mineral Kingdom," 2nd ed. i. p. 275.)

until horse-gins were erected for drawing the water and ore, and *loughs* began to be driven for drawing off the water.

Farey thus explains the *loughs* or levels:* "Where deep valleys intersect a mineral district, it is often found practicable to begin in the valleys, and by driving or cutting a small tunnel, lough, or water-level, and supporting the same with wood, stone, or bricks, to relieve or lay dry the mineral vein."

"The mines or meers of ground became consolidated, or the property of them united, and the mines being connected below, the ore and vein-stuff was carried to particular shafts, to be drawn, and on the hillocks, of which *coes*, or small buildings, were in time erected for stowing the ore, tools, &c., and sheds for the accommodation of the ore-dressers, or those who separated the smaller portions of ore from the vein-stuff, a process which was probably little attended to in the earlier periods of these mines."

"All the lead ore which is dressed ready for sale in the King's field is obliged to be measured in the presence of the barmaster before it is removed from the mine, for which purpose a rectangular box is used in the Low Peak 28 inches long, 6 wide, and 4 deep, called a dish, and reputed to hold 14 Winchester pints, when level full; while in the High Peak 16 pints are reckoned to the dish.

"In measuring the ore at present (1811), every twenty-fifth dish which is measured is taken or set aside by the barmaster, as the King's lot, cope, or duty; and in case of a composition being due to soughers, who free the mine of water, at one-sixth in Wirksworth, and of tithe being payable as one fortieth in the same place, the barmaster causes every sixth and every fortieth dish which is measured to be set aside or laid in a separate heap for the use of the parties, and so of the lord of the manor's dues, if any such are payable where the mine is situated, as at Crich, &c. The *meer* in a pipe-work, or horizontally extended mine, is fourteen yards square."

Farey further describes the methods of working Lead Mines as follows. The practices described do not appear to have undergone any change through the eighteenth century, and were continued until the nineteenth century nearly unaltered: "Except where horse-gins are used, it is not common to sink very deep drawing-shafts to lead mines, especially as dividing the same into several lifts or *turns* often suits the trade of the mine, such turns or under-ground shafts being connected with each other, by means of short *thurls*, or horizontal galleries. The persons who sink mine-shafts are generally called shafts-men, and those who drive levels or gates, level-men, or gate-men. The miners who dig the ore are usually called *copers*, from their working at a certain *cope*, or price per [redacted] load of ore which they get. In some large works the price per [redacted] load is fixed at the commencement of each quarter; but where [redacted] productive, bargains of this nature are generally made [redacted] quarter, viz. for six or for seven weeks alternately. It is not [redacted] for the owners to advance any of the cope-money on account, [redacted] of the bargain, the miners having dressed up the ore that [redacted] got, it is weighed, if by the ton, or measured if by the load, in [redacted] of the

* Farey's "Derbyshire."

barmaster and his employers, and at the pay-day, which is usually a fortnight after the ending of the quarter or half-quarter, they receive the money for the quarter's reckoning.

"In the working of the deep rake veins, a roof of *Bunnings*, or of shale or toadstone, may be supposed over the miners' heads, who in some works drive only one *stoop* of work, that is, a height of four or six feet before them; while in others, where many men are employed, two or three stoops are carried on at the same time, the upper one being kept forward two or three yards, and the next as much before the lower one or *sole*, like steps, by which means the miners do not interfere with each other materially."

"The face of a *stoop* or forefield of the mine is seldom worked upright or straight, but is hollow in the middle, to suit the swing of the miner's pick, many of whom pride themselves much on the neatness of the face of work which they preserve, in moderately hard veins, where the pick alone is sufficient for the work. In Gang mine, where a *slickenside* runs through the vein, the miner avails himself of a curious property attending such veins, by drawing *laces*, *stoops*, or *nicks*, at about six inches apart and four inches deep, with the point of his pick from top to bottom of his face of work, which he then leaves for several hours, and, on his return, finds all the vein-stuff is *furrowed*, *spelled*, or *slappeted* off, and laying on the sole ready got to his hands. But it more commonly happens that strong picks, hammers, and strong iron wedges, or even frequent blasts of gunpowder, are necessary for loosening and getting the ore and spar, the former of which, as well as the lumps of spar or vein-stuff which he judges to contain ore, the coper collects into shallow oval spel baskets called *whiskets*, and these are taken from him by the boys called *setters-on*, who carry the same a stage of about twelve yards along the hole or gate of the mine, and then hand them to other boys who carry them a similar stage, each returning with an empty basket, until the stuff thus reaches the kibble or small barrel at the bottom of a turn or underground shaft, which kibbles, when full, are wound up by the turn-drawers, who convey it to another turn, and so on, until the kibble of stuff reaches the top, unless horse-gins are used, when the *setters-on* carry their whiskets of stuff to the bridging-floor or foot of the shaft, when the bridger empties them into a larger tub called the gear-barrel, which, when full, is drawn up the shaft.

"The Coper or miner throws the refuse vein-stuff and parts of small riders, or the skirts of narrow parts of the vein which he has found it necessary to blast or cut down, behind him in the sole, until a shift or shift and a half of work is performed, when he begins drawing the bunning or stemples forward. This consists in forming a hole in the solid side or skirt, striking out a sort of upright *mortice* in the skirt, whose bottom is level with the opposite hole. He then chooses or cuts a stemple or booth of the right length—that is, a piece of wood of the size of a man's arm, or larger according to circumstances, having one end cut to a round blunt point, called the egg end, and the other square and a little lessened, called the head.

"This round point he enters into the hole cut in the skirt, and the other into the top of the mortice, or groove cut in the opposite skirt, and then by hammer or his mattock drives the square end down to the bottom of the

mortice, by which means the stemple becomes a firm and immovable strut across the vein; when four or five of the stemples are thus fixed, flat pieces of wood, called *fails*, are laid across these, and then the coper proceeds to lay up his *deads*, or pieces that contain no ore, on to these fails, called the bunning; after building up a kind of wall in front with the larger lumps, the remainder are thrown over this on to the fails; more of the stemples and fails are then fixed, and the deads are thrown on them, until the sole is quite cleared, when the getting of the ore is resumed as before.

"Previous to the use of gunpowder in mining, fires of dry wood were made against the forefield of the vein, which, owing to the heat, loosened and slappeted off. The mining laws provide that such fires should not be lighted or any smoke made in a mine during mine hours, or mineral time of the day, that is, from eight to four o'clock. By means of those fires it is surprising to see what narrow veins, mere *scrins*, the old men contrived to work for great distances into the rock, using long-handled rakes or hoes to draw out the loosened ore and spar, and hence the name of *rake veins* is said to have originated."

Farey gives the following as the names of lead ores in Derbyshire, "with reference either to size, purity, structure, or kind:" *belland, bing, blue, fell, galena, glance, goods, green, hillock, lead-glance, leaf, peasy, pippin, potters, scrogs, smitham, steel-grained, tag'd, toots, white, wicks, yellow, &c.* This shows that the lead ores of Derbyshire are very numerous, but the general produce is galena (sulphuret or sulphide of lead, or blue lead ore) crystallised in cubes; but square and hexagonal pyramids and other forms of this lead ore sometimes occur.

"Within a few past years (1811) the miners of Derbyshire have discovered a *white lead ore* (carbonate of lead), which was previously taken for a useless spar, and was either left in the mines or buried in the old hillocks, from which considerable quantities have since been extracted. This carbonate of lead is often called wheatstone" (*Farey*). In nearly all cases this white carbonate of lead is the result of the decomposition of the sulphide of lead (*galena*), either by the action of air or water.

A Green Lead Ore, probably a phosphate, has been found in Brassington, Great Hucklow, Tideswell, and Winster; and, according to Farey, also in the following mines: Calver, Flagg, Great Longedon, Hartington, Hassop, Mongash, Sheldon, Wensley, and Wirksworth.

The mode of selling lead ore at the end of the last century was evidently of considerable antiquity. A very clear account is giv [redacted] ey, and, as it is curious, his words are retained:—

"Formerly it seems that considerable quantities of [redacted] yshire lead ore selected from the largest and most pure, or *Bing* [redacted] old in that state to the Staffordshire and other potters to grind, fo [redacted] the glazes of their common wares, and hence such was called *potte* [redacted] t at present all the lead ore of the county, and even that produ [redacted] e mines in Warslow in Staffordshire (with the exception of Act [redacted] he Duke of Devonshire has a cupola for his own ore) is brought [redacted] yshire to be smelted. Owing to the division of the mines in [redacted] into such

numerous shares, no miner in Derbyshire now maintains a cupola.* . . . . Formerly, when the mines of Derbyshire were in their most flourishing state, there were markets at Wirksworth, Winster, Chesterfield, and some other places, but such is not now the practice, for almost every miner, sougher, or tithe-owner, &c., has some smelter to whom he sells his ore regularly, and such smelter attends the ore-measurings."

The price of lead at Hull in Yorkshire seems to be the rule principally followed in fixing the price of ore from time to time in Derbyshire; and though the ancient method of measuring ore is still adhered to, yet weight and scales are now generally used in the *ore-cob* at the time of measuring, and three dishes at least, taken indiscriminately from each of three sorts of ore, viz. *bing*, *peasy*, and *smitham* (belland being always sold by weight at the rate of 53 to 60 lbs. per dish), are weighed, and the average is noted by the barmaster and buyers present. The usual practice of the smelters was to consider 58 lbs. as the standard weight of a 14-pint dish of ore, and to allow the miners, to whom they were regular customers, half the price per ton for their ore that lead bore per *Fother* or *Fodder* at Hull (2,340 lbs.) at the time of taking up each parcel of ore, and that parcels of ore weighing less or more than the above standard weight per dish (from the average of three dishes as above), were deducted from, or allowed extra at the rate of 10s. per ton of ore for each pound that the dish fell short or exceeded the standard.

"The carriage of ore (1790), in common with that of every other article, was on pack-horses formerly, a drove of such horses being called a *jag*, and persons carrying ore for hire were called *ore-jaggers*, a name still (1802) applied, though carts and waggons are universally used in these parts, except a few pack-horses that may yet be seen about Buxton, Hathersage, and the very mountainous parts, the mules used in bringing coals and ore to the Whiston copper works in Staffordshire, and the horses and asses used to supply some of the poor with coals from the pits in different parts. The average price of carrying ore in 1808 appears to have been 1s. per ton per mile" (*Farey*).

In the boyhood of the author droves of mules were to be constantly seen in Cornwall carrying the tin ore from the mines to the tin smelting-houses.

In the early periods of mining, in Derbyshire as in other places, the ore was smelted on the tops or western brows of high hills—these being chosen as being most exposed to the prevailing winds—by fires made of wood, and

* Bache Thornhill, Esq., of Staunton, in the Peak, is the only person in Derbyshire who works lead mines of any consequence on his own account (the end of 1700) without partnership. Sir Joseph Banks began to sink some shafts at Overton for the purpose of employing the miners who were suffering by the stopping of Gregory and Westedge mines.

"In general as small shares as 48-ths, 96-ths, or even 384-ths, and 768-ths are held in the Derbyshire mines, and the very smallest mines have often many partners concerned in them, originating in the mode of granting tithes originally by the barmaster. The facility with which shares are sold and transferred, by entry in the barmaster's book, and in numerous consolidations of tithes, which have necessarily taken place to form large works, such as what is now (1802) called the Gang Mine, and others of that class. The owners of manors and estates within the King's field, who are possessed of mineral rights, none of them commute with the miners for fixed rents, but all take their cope or share of ore in kind, at each ore-weighing, as the King, the soughers and the tithe-owners, to which last impost is paid only in Eyham parish, and in Wirksworth, including Cromford and Middleton. The pretence of claiming tithe of lead ore is said to have been that the ore *grew and renewed in the vein*. In 1780 the gentlemen miners met the clergyman, and agreed on 1-20th as the tithe-owner's share; but the miners all resolved to pay no more than 1-40th."—*Farey*.

blown by the wind only. Piles of stones were made round the fire, and probably arches formed underneath them, to favour and increase the action of the wind.

These old hearths were called *boles*, whence many of the highest hills near the lead districts obtain their names. Anciently the miners claimed the right of cutting wood and timber for the use of the mines, and for smelting, not only from all wastes and forests within the King's field, but from any other of the King's forests; and Farey says, "There are people living yet (1802) in Matlock who have assisted in fetching timber under this privilege from Needwood Forest, in Staffordshire, for the use of their mines in Matlock." . . . . "It seems probable that the ports of the Trent and the Humber were always the destination of the *pieces*, or half pigs, of lead made in Derbyshire, from the distance which the ancient boles stretch out in an eastern direction from the Limestone district in which the mines are found, and hence Chesterfield was always a great mart for lead, and particularly so since the opening of the Chesterfield Canal to the Trent in 1776."

In 1800 the following *ancient boles* were known to have existed:—

Bank (near Holmsfield), half-mile S.W.
Baslow, N.E. of the colliery.
Bole Hill, S. of Sheldon, in Bakewell.
Ditto, quarter mile N.W. of Upper Hurst, in Hatherage.
Ditto, S.W. of Ningerworth.
Ditto, N.W. of ditto.
Chatsworth Old Park Plantation, S.E. of Baslow.
Cold Harbour, in Lea.
Cromford Moor, S. of the Bridge.
Eyam.
Holy-moor Top, N.E. of Harwood cupola.
Matlock.
Slag Hills, S. of Batherley.
Stanton, in the Peak.
Three-birches, Pudding-pie Hill, W. of Brampton.
Unthank, quarter-mile W. in Dronfield.

Farey informs us: "These very ancient *boles*, or wind-hearths, were succeeded by *slag-mills*, or treadles, almost like a blacksmith's forge on a large scale, blown by bellows, worked by men or by water, one of which is still seen (1801) attached to each of the cupolas that can command a stream of water. Near one of these ancient slag-mills in Bonsale Dale, the slag of it used some years ago to be laid into the road, to be ground to dirt by the wheels of carriages, and then used to be scraped up and dried and remelted on the hearth, and strong iron rollers were used for crushing the slag for the same purpose. At the old hearth at Harleford Bridge, S. of Hathersage, such waste of ore was formerly made as to have employed a set of buddlers for ten years past, turning over the rubbish for three yards deep or more. Some of the ore thus obtained seemed to have passed through the fire and some not, which I account for by the floods of the Derwent, which have probably at different periods swept down their mills, coes, &c. Thirteen hundredweight of the ore and slag thus procured, generally pro-

duced from one and a half to four pieces of lead at the cupola, as the buddlers informed me.

"Anciently, it seems, that the Crown claimed the right of smelting all the lead ore which was obtained in the King's field, and took toll or duty of it; and it is said that their boles were so ill-managed, and the exactions at them were such that the mines were in a great measure disused, until at length, in order to revive the mining of the district, the Crown agreed to accept 6d. per load of nine dishes of ore from the smelter in lieu of the smelting claim, which continues yet to be paid to the barmaster at the time of measuring ore. The mines within the manor of Haddon and Hartle were also restricted by the custom of those manors from smelting their lead but at the lord's hearth, which occasioned the Duke of Rutland to maintain one of the old hearths at the N.W. of Great Rowsley village, long after they had been elsewhere disused. At length, about 1780, the miners agreed to pay 9d.. per load (of 144 pints) to his Grace to be at liberty to smelt their ore where they pleased, and this last of the hearths for smelting ore was disused and pulled down. The remains of one of these old slag-mills, with some slag but imperfectly deprived of its lead, was found 200 yards N. of Somerester iron-furnace in Alfreton."

The *cupolas*, or low-arched reverberatory furnaces, now (1801) exclusively used for the smelting of lead ore in Derbyshire, were introduced from Wales by a company of Quakers about the year 1747, the first of which was erected at Kelstedge, in Ashover, but this is now disused and pulled down, as will be seen from the following *List of Cupolas* in, and near, Derbyshire:—

Barber-fields, in Dronfield (formerly).
Barbrook, in Baslow (and Slag-mill), T. and J. Barker.
Bonsal Dale (and Slag-mill), Evans and Co.
Bradwell, Benjamin Barber.
Bretton, in Eyam, Samuel White.
Calow, E. of Hathersage, late Wm. Longdon.
Copy Nook, in Stanton Harold, Leicestershire, Earl Ferrers.
Cromford Moor (Steeple House), Charles Hurt.
Devil's Bowling Alley, in Alderwasley, Francis Hurt.
Ecton, in Warslow (and Slag-mill), Duke of Devonshire.
Harwood Moor, near Loads, George Barker and Co.
Kestledge, in Ashover (two formerly).
Lea, near Cromford (and Slag-mills), Shore and Co.
Lermsdale, in Matlock (formerly).
Middleton Dale, in Stony Middleton, George Barker and Co.
Stannage, in Ashover (and Slag-mill), Sykes, Milnes, and Co.
Stannage, ditto, George Barker and Co.
Tutley (and Slag-mill), George B. Breaves.
Via Gellia, in Bonsel Dale, Saxleby and Co.
Weddsworth, E. of the town, Charles Huart.

Farey remarks, when he published this list, 1801, "Several of the smelters are doing but little, and some have their works shut up occasionally, owing to the supply of ore being now greatly inferior to what it was about twenty years (1780)." At Middleton Dale ore is smelted for the miners and

'buddlers' at 14s. for a charge of ore, usually about 18 cwt., and 13s. for a charge of 'belland' or dust ore, usually about 12 cwt., and in these cases the miners sell their pieces of lead, instead of their ore, to some of the smelters, who are, I believe, the only lead-dealers in the district."

CUMBERLAND.—The early history of the mining district of Alston Moor is but little known. There is satisfactory evidence that the Romans penetrated into this region, silver denarii having been found at Hallhill, near the town of Alston. Mr. Thomas Sopwith * remarks: "It is improbable that so extensive a work as the great Maiden Way, or great Military Road, constructed by that warlike people (the Romans) would be prosecuted without discovering lead ore in some of the numerous veins which it crosses; and, at the Roman station at Witley, in Northumberland, pieces of lead have been found, as well as in numerous other places."

There is satisfactory evidence of the antiquity of mining in the charters granted to the miners of "Alderston."

They had royal protection in 1233, and renewed in 1236 and 1237. In 1282, Richard II. granted to Nicholas de Veteripont (Vipond) "the manor of Alderston, to hold in fee of the King of Scotland," reserving to himself and the miner various privileges, especially such as belonged to the franchise of Tindale, within which Alston was then comprised. The miners, who farmed their mines of the King, and worked veins containing silver ore (this is not correct; they worked veins of lead, which produced several ounces of silver to the ton), claimed a right to take any wood that should be near their mines, and also at their will and pleasure to use and dispose of such wood for burning, dispersing, and smelting; for paying the workmen their wages, and to give to the poor workmen of the mines.

These claims were disputed by Henry de Whitby and his wife Joan, "who impleaded" several of the miners for cutting down and carrying away their trees; and further charged them with having sold large quantities of wood from which the King received no benefit.

King Edward III., in the seventh year of his reign, confirmed the privileges previously granted to Robert, son of Nicholas de Veteripont; and in the following year the "monetarie," or coiners, had their liberties confirmed by the King. This proves that the silver obtained from the lead raised was coined within the manor of Alston. In the twenty-fourth year of Edward the Crown "exemplified some charters of privileges; and again, in 1356, very large additional privileges were granted."

Henry V. let the manor and mines of Alston to William Stapleton, Esq., at an annual fee-farm rent of 10 marks, payable at the exchequer of Carlisle.

Alston afterwards became the property of the Hyltons of Hylton Castle, in the county of Durham; and in 1611 a considerable portion of the lower parts of the manor, adjoining the rivers Tyne and Nent, was granted in leases for 999 years by Henry Hylton, subject to the payment of certain annual rents, which amounted to £64, but, with some encroachments taken off, are now £53, and a fine of twenty times the rent every twenty-one years.

The following is a copy of portions of a "Lease from Henry Hilton to

* "An Account of the Mining District of Alston Moor, Weardale, and Teesdale, in Cumberland and Durham." By T. Sopwith, Land and Mine Surveyor, Alnwick. 1833.

Henry Wallas, of a tenement in Alston Moor for *one thousand years*," which was granted in the year 1611:—

"This indenture, made the last day of August, in the eighth year of the reign of our Sovereign Lord James, by the grace of God, of England, France, and Ireland, King, defender of the faith, &c., and of his reign in Scotland the five and fortieth, and in the year of our Lord God 1611, between Henry Hilton of Hilton, within the county palatine of Durham, esquire, of the one part, and Henry Wallas of Wanwood, within Alston Moor, in the county of Cumberland, yeoman, of the other part, &c.

"Now that the said Henry Hilton, son and heir of the said Thomas Hilton, as well as in consideration of the sum of four hundred pounds of lawful money of England to him the said Henry Hilton, to be paid by the said Henry Wallas and the rest of the tenants of the said Henry Hilton in Alston Moor, for the payment whereof the said Henry Wallas and the rest of the tenants have given such security to the said Henry Hilton every man for his part and portion of the said four hundred pounds as the said Henry Hilton hath accepted, as also in consideration of twenty years' rent to be paid unto the said Henry Hilton, his heirs, executors, administrators, and assigns, or some of them, for a general gersome and fine, at the first of all the tenants of the said Henry Hilton, in Alston Moor aforesaid, their heirs, executors, administrators, and assigns, and every one of them severally," and so on. Again, "Henry Wallas shall well and truly satisfy, content, and pay unto the said Henry Hilton, his executors or assigns, the sum of £14 18s. 4d., of good and lawful money of England, being the full and entire sum of twenty years' rent hereby reserved upon the messuages, lands, and tenements, that is to say, £7 9s. 2d. thereof at St. Andrew's Day next ensuing, and £7 9s. 2d. to be paid at St. Andrew's Day which shall be in the year of our Lord 1611, which said sum is for a fine and gersome of the first twenty-one years from the beginning of this lease, &c.; and all other easements, profits, and commodities whatsoever to the said messuage or tenement, and all other the premises belonging or in anywise appertaining, or thereof accounted, reputed, or taken as part or parcel, or used and occupied as part and parcel thereof, together with house boot and hedge, boot to be taken at the sight of the officer there for the time being, so often and at all times when need shall require, and as it hath been used and accustomed to be spent or used in or upon the said messuage or tenement and other premises, to have and to hold, occupy, possess, and enjoy the said messuage and tenement, and all other the premises with the appurtenances thereunto belonging, from the 9th day of the month of September which shall be in the year of our Lord 1621, unto him the said Henry Wallas, his executors, administrators, and assigns, and every of them, unto the full end of the term of 1,000 years therein next after ensuing, fully to be compleat, fulfilled, and ended. Such other person or persons as shall happen to have the interest of this lease shall well and truly, from time to time, after the expiration of every number of twenty-one years, so often as twenty-one years shall by effluction of time be spent and run out, to be accounted and reckoned after the beginning thereof, satisfy, content, and pay, or cause to be well and truly satisfied, contented, and paid unto the said Henry Hilton, his heirs and assigns, or to

such person or persons as shall happen to have immediate reversion of the premises, or to some of them, the sum of £14 18s. 4d., of good and lawful money of England, in the name of a fine or gersome, being twenty years' rent, herein by these presents reserved at or upon the end or expiration of every twenty-one years, as often as the number of twenty-one years shall by effluction of time run out during the said term of 1,000 years, the said several sums of £14 18s. 4d., so often as they shall happen to grow due during the said term, to be paid in this manner and form, that is to say, £7 9s. 2d., being the one-half thereof, to be paid at or upon the Feast of St. Andrew," &c. &c. &c.

Many such leases are in the custody of Mr. Adam Walton, the moor-master of Alston Moor, and are still preserved in Lowbyer Manor Office, Alston.

In 1629, the lead mines, after a survey had been made, were reported to be nearly exhausted; and the whole manor, with houses at Lowbyer and Mack Close, and a corn-mill at Alston, was sold to Sir Edward Radcliffe for £2,500, and remained in that family till the confiscation of the estates of James, Earl of Derwentwater, in 1716. The mines were granted in 1734 to the Royal Hospital for Seamen at Greenwich, and the manor remained in the hands of commissioners and governors in trust for that institution until, on the Government abandoning the system of the Hospital at Greenwich, it was transferred to the Admiralty.

The evidences of copper having been formerly worked on Alston consist of a copper wire, or a cart-pin, in possession of a gentleman at Allenheade, and a spoon of the same metal, found in 1829 (*Sopwith*).

In 1760, Sir Walter Calverley Blackett introduced many improvements in the system of working the lead mines in this locality. Mr. Smeaton, the celebrated engineer, was for three years one of the receivers of the Freemond Hospital estates, and he projected and commenced the aqueduct of Nentforth Level, and he introduced cast-iron railways into the London Lead Company's works. To Smeaton is also due the discovery of the Rampgill vein, or, more strictly speaking, of its amazing value.

In 1780, Messrs. Walton & Co. bought a mine at Nenthead for £205, and being fortunate, they engaged in several other mines on Alston Moor. In 1782 they began to work in Farnberry vein, which was supposed to be exhausted, and they were richly rewarded for their bold adventure.

Tin pipes were first used by Lord Carlisle and Co. for ventilating in Tyne-bottom mine. Mr. Stagg introduced iron pipes at Rampgill, and Mr. Thomas Dickinson, the moor-master, of Alston Moor, made use of lead pipes for the same purpose in ventilating Nentforth Level.

In 1796, a Cornish miner, Richard Trathen, introduced an improved mode of washing lead ores, and, from the slimes rejected by less experienced washers, he obtained much wealth.

Such was the condition of lead mining in Alston Moor at the close of the eighteenth century.

The mines of *The Lake District*—around Keswick—are of great antiquity. "Indeed," says Mr. John Postlethwaite,* "there is good reason for believing

* John Postlethwaite's "Mines and Mining in the Lake District."

that mining has been carried on in this district for about two thousand years and much of the history of the Lake country is associated with its mines."

In "Camden's Britannia," Keswick is spoken of as "a little market town, long since noted for its mines, as appears from a certain charter of Edward IV., and at present inhabited by miners." This will be about 1607 Of Derwentwater the same authority writes: "It contains three islands, one the seat of the Ratcliffe family, the second supposed to be the one on which St. Herbert lived a hermit's life, and a third inhabited by German miners."* The Barrow mine is a very ancient one, having been wrought extensively with "stops and feather" long before gunpowder was employed.

Roughtengill mine was in all probability worked at the same time as Barrow, as was also Higgeth and Haygill mines.

The copper mines of this district are noticed in the previous chapter.

CARDIGANSHIRE.—We have no account of any mining operations in Cardiganshire which can be considered authentic previously to the reign of Henry VII. (1485). In the "History and Antiquities of the County of Cardiganshire," by Samuel Rush Meyrick, published in 1810, the author speculates on the probability that the Britons wrought the mines of Cardiganshire for silver and gold. He infers this chiefly from the Triad which celebrates Caswallan, Manawydan, and Llew Llawgyfes as three chieftains distinguished by the possession of golden cars. Meyrick states that no Roman coins, or any vestiges of Roman workings, have been found in Cardiganshire. However, since 1810, coins, evidently Roman, have been found near Aberystwith. Sir John Pettus, in his "Fodinæ Regales," published in 1670, says: "These works in Wales, with some others in Devonshire, Somersetshire, and Cornwall, as far as tradition can assure us, were anciently wrought by the Romans; by the Danmonii in Devonshire and Cornwall, by the Belgæ in Somersetshire, and by the Dimetæ in Cardiganshire." He gives some drawings of lead mines in his book, and designates them as the Roman mines, but their being Roman workings is doubtful.

King Henry VII., in the first year of his reign, created by letters patent Jasper, Duke of Bedford, and others, "earls, lords, and knights," commissioners of all his mines of gold, silver, tin, lead, and copper, in England and Wales, Sir William Taylor being made the comptroller of this commission. We have no reliable information of the action taken by this commission. Little appears to have been effected during the reign of Henry VII. or in that of Henry VIII. Sir J. Pettus† says: "But before Henry VIII. his death, almost all the treasures of his father and his own were consumed, and what remained was left to Edward VI., an infant, whose experience would not guide him to the care of such affairs. Then followed Queen Mary," in whose reign the mining commission was neglected, and "stood neglected above seventy years." The earliest intimations we have of the real produce of any of the mines in Cardigan is that given in a trial as to a "Mines Royal" in Westminster Hall. *Est-kyr-hyr* was claimed as a mine rich in silver, and therefore a Mines Royal. Proof is said to have been given in the court that this mine produced lead giving 60 lbs. of silver in every ton, whilst the

* Gibson's "Camden's Britannia." † "Fodinæ Regales."

proprietor stated that it only contained to the value of 4 lbs. of silver to the ton."*

It has been already stated that Elizabeth caused several German miners to be brought into this kingdom. Houghsetter was one of these, and he with his family settled in Cardiganshire, and for four years actively prosecuted the search for mineral treasures over that county. The Corporation of Mines Royal worked for several years many of the lead mines of Cardiganshire. Sir J. Pettus says these were the "Mines Royal at Coomsumblock and the Darren Hills, Cwmervin, Goginean, Talybont, Coomustwith, Tredole, Thruscott, and Rossvawre, which were the old Roman works." He remarks, "They wrought several mines with good success," but they were eventually let for the annual rental of £400. They could not, therefore, have been very profitable.

The mines of Cardiganshire became, during the latter half of the sixteenth century, the property of Sir Hugh Middleton, who was the sixth son of Richard Middleton, governor of Denbigh Castle in the reigns of Mary and Elizabeth. He is said to have, in the first place, sought for coal. Being disappointed in finding any, he settled in London, as a goldsmith, and then farmed the principal lead mines from the Governor and Company of Mines Royal for £400 per annum.

Hugh Middleton drained the mines more effectually than they had hitherto been, and working them deeper than the German miners appear to have done, he was successful in finding very rich lead ore. It is said that the ore of one mine—probably Cwm-symlog—yielded 100 ounces of silver to the ton of lead. It is certain that he realised a large fortune from his speculations in the Cardiganshire mines. A profit of £2,000 a month is stated to have been derived from Cwm-symlog and the neighbouring mines.†

It is recorded that in 1604 three thousand ounces of Welsh bullion were minted at one time in the Tower. Hugh Middleton was a man with considerable energy and determination. In 1608 he proposed to bring the New River from Ware to London, promising the Lord Mayor that the undertaking should be finished in five years. Upon this truly national work the profits of the Cardiganshire mines were expended, and Middleton was obliged to apply to the Government for money to complete his task. James I., with his Court and the Lord Mayor, witnessed the first issue of the water from the head at Islington, and the King conferred the honour of knighthood on Middleton, and subsequently a baronetcy.

After the execution of this great work Sir Hugh Middleton appears to have become so poor as to be under the necessity of working as a surveyor. We, however, find him in 1639 disputing with Sir Richard Pryse about the mines of Talybont, and a trial of considerable importance was the result. Sir J. Pettus thus quaintly notices the fate of Sir Hugh Middleton:—

"Had he not diverted his great gains to the making of the New River from Ware to London, certainly he would have been the master of a mass of

* Watson's "Chemical Essays," vol. iii. p. 307, ed. 1782.

† "Opera Mineralia Explicata," and Watson's "Chemical Essays."

wealth; but great wits and purses seldom know how to give bounds to their designments, and by undertaking too many things fail."

Until the year 1641 the Earls of Pembroke continued the governors of the Company of Mines Royal, but from 1647 no governor was chosen. The mines of Cardiganshire were actively worked by Mr. Thomas Bushell, who was the secretary of Sir Francis Bacon. Bushell was a man pretending to some scientific acquirements, and certainly possessing good literary capabilities. He published, in 1642, "A Just and True Remonstrance of His Majesty's Mines Royal in the Principality of Wales;" also "The Case of Thomas Bushell truly stated, with his Progress in Minerals,"* in 1649. Several other publications issued from his pen, and he edited a new edition of "Bacon's Articles of Inquiry." Bushell states that "In the mountains of Broomflyd, Talybont, Goginan, Cwm-erven, and Darren, there were great quantities of lead and silver, and I bought those mines, which had been granted to Lady Middleton by King James for £400 down, and £400 per annum during the continuance of her interest therein." Mr. Bushell worked those mines deeper than Middleton had done, and at Cwm-symlog, "he, being flushed with this (Sir Hugh Middleton's) success, cut a measured mile to find this vein, to three and four yard deepness, at no small charge; and seeing Sir Hugh, by an engine, had wrought it several yards under water, the patentees endeavoured to bring up an adit to go under this work at the expense of £10,000." The patentees named appear to have been Sir Francis Godolphin and Sir Edmund Wallcopp.†

Thomas Bushnell, or Bushell, Esq., it is stated by another authority, was servitor of Lord Chancellor Bacon, and seems to have devoted his life to mining speculations, being buoyed up with the most sanguine expectations of recovering "mineral riches out of the hardest rocks." In 1658 he undertook to recover certain drowned and deserted works, being "the forlorn hope of that great engineer, Sir Bevis Bulmer, at Rowpits, near Churton minery in the Mendips, upon which it is said £10,000 had been expended out of Queen Elizabeth's purse to perfect the same, but could not; but at the moment when Bushell's hopes were about to be realised he was cruelly thwarted by the malice of certain persons."

In a letter to Charles, Prince of Wales, Mr. Bushell says: "Nothing doubt but that, in process of time, I shall be able, with the assistance of my co-adventurers, and help of their greater purse and fortunes, to make these British hills, as in situation so in esteem too, resemble the West Indies, or at leastwise, those renowned mines in Saxony."‡

Those mines were for a period exceedingly profitable, and availing himself of the indenture of Charles I., dated 30th July, 1647, he established a mint at Aberystwith. The privilege is granted for the following reasons: "That there are, and likely to be, many hopeful mines discovered in the

* The whole title is a curiosity. "The Case of Thomas Bushell truly stated, with his progress in minerals, and the desire of several merchants and others that are ready and willing to advance so good a work for the benefit of the nation, humbly tendered to the serious consideration of the honourable House of Commons, and all other persons in authority, whether civil or martial, that are desirous to advance the trade of the nation, supply the necessities of the poor by discovering the hidden treasures of the earth, preserve the lives of many poor creatures from untimely death (who are now destroyed in their prisons for petty felonies) which might otherwise be serviceable to the Commonwealth." London: 1649.

† William Waller's "Report on the Cardiganshire Mines."

‡ Waller's "Account of the Mines in Cardiganshire."

principality of the mountains in Wales, where it is conceived are great quantities of silver, though by reason of the unskilful way of working the said mines the same are either drowned by water when the ore comes to a considerable quantity and rich in quality, or that through ignorance the goodness of the ore is not known to the owner, and so is transported to other nations for 'potter's ore,' * out of which strangers refine silver, to the great loss and prejudice of His Majesty's service."

This company made a large outlay; but they failed to raise much ore at Cwm-symlog, and they never found the lode which was so profitable to Sir Hugh Middleton. At Goginan, Bushell was more successful, and Mr. Waller says: "He kept a mint at work at the silver-mill in Cardiganshire, for the bullion he had at this mine, and is said to have clothed King Charles the First's whole army from part of his profit in this work." Certain it is Bushell sacrificed his fortune in the King's defence during the civil wars, and placed himself at the head of a regiment of miners, which he had raised in support of the royal cause. Aberystwith Castle was besieged and taken by the Parliamentary forces, and this led to the mines being abandoned. Bushell must at one period have been a man of considerable wealth, since he constructed a harbour at Lundy Island.

In 1658 these mines were visited by Ray,† who thus describes his visit in his "Itinerary": "September the 6th, I travelled to Mahentler (now Machynlleth), and then to the silver-mills, where I saw and learned the whole process of the work of melting and refining of silver. They have two sorts of ore, the one rich, of Dorrens (Darren), and the other poorer, of Talybont. They mix these, six parts of Dorrens with four of the other, because the former, being rich, will not melt off the hearth without such a quantity of the latter. Then they carry it in a barrow from the store-house to each smelter's several bing, where it is melted with black and white coal (that is, sticks cut into small pieces, then slit and dried)."

In 1662 Ray states: "Thursday, June 3rd, we travelled over the sands, and so came round about by Talybont, to the silver mills, and viewed the mint at Talybont, and took as exact a description as we could of the silver works."

After the Restoration the mines again passed into the hands of the Company of Mine Adventurers. Little appears to have been done at the mines until about 1667. When Sir John Pettus published his "Fodinæ Regales," in 1670, they were not worked "effectually," as the knight tells us. Pettus gives the following account of the mines at this time: "A stream of water, three miles from Talybont, falls into four great wheels, whose turning guides the rising and falling of the bellows and stampers. At the great stamping-mills there are five hearths, with backs, checks, work-stones, iron plates, &c.; five pairs of large smelting-bellows, &c., one great pair of scales with weights." Several other articles are named; and in the smelting department ten men were employed. The materials in the ore-house, the old mint-house, the stamping-mills, the refining-mills, the red-lead mills are then stated, and it appears that in these eleven men were employed. At the Mines Royal at Talybont four washers, a smith, and a carpenter were

* "Potter's ore" is lead ore free from silver, which is prejudicial, as giving colour to the glazes, &c., for which it is used.

† John Ray's "Itinerary," and other works, from 1704 to 1738.

employed. A list is given showing the number of tubs and sieves, and states "that four dozen ore-bags lie in the carriers' hands and custody."

In 1670 "Articles of Agreement and Subscription between H.R.H. Prince Rupert and divers noble and honourable persons and others, undertakers for working the Mines Royal in the counties of Cardigan and Merioneth, in the principality of Wales." * From these articles we learn that the undertaking was to consist of forty shares and no more, of £100 each. The committee consisted of Sir Paul Neville, knight, Sir Francis Cobb, knight, and seven other gentlemen, with Mr. Edward Blackwell for treasurer. The committee was to meet at the Rolls Chamber, in Whitehall, every Tuesday in the afternoon in term time. They leased from the Mines Royal for one and forty years "the mines of Comsymlock, Goginan, Cwm-erfin, and Talybont, in Cardiganshire, and all the mines near Barmouth, in Merionethshire;" and they also "purchased the lease of the smelting-mills in Skybery Coed, in the parish of Llanyhangell Generoglyn, in Cardiganshire." The directors of the company quarrelled, and the mines were neglected.

In 1690 some mines were discovered on the Gogerddan estate, belonging to Sir Carberry Pryce, who, under an Act of Parliament in the first year of William and Mary, took in several partners, and "divided his waste into 4,000 shares." He sent to the North of England, and secured the assistance of Mr. Waller as his agent at £200 per annum. There arose an action between the Society of Mines Royal and Sir C. Pryce; the points in dispute were settled in his favour, but he died without issue, and Mr. Edward Pryce sold his interest to Sir Humphrey Mackworth for £15,000. In 1699, Mr. Waller made a report on the condition of the mines, which was afterwards referred to Sir H. Mackworth and William Player, Esq., of Gray's Inn. This document shows that about a hundred men were at that time employed. It does not appear that any large quantity of ore was raised, but the miners were working upon several veins, which were then considered to be of great promise. The ore was, at this period, sent to Neath to be smelted, where Sir H. Mackworth made considerable improvements in the operations for refining silver and manufacturing litharge. He also improved the arrangements necessary for loading and unloading vessels. No effort was neglected which promised to raise these mines in the estimation of the public. Amongst other *methods* a long poem "To Sir Humphrey Mackworth, on the Mines of the late Sir C. Pryse," was published by Yaldon. The following lines sufficiently indicate the character of this work:—

Thy fam'd inventions, Mackworth, must adorn
The miner's art, and make the best return;
Thy speedy sails and useful engines show
A genius richer than the mines below.
Thousands of slaves unskilled Peru maintains,
The hands that labour still exhaust the gains;
The winds thy slaves, their useful succour join,
Convey thy ore, and labour at the mine;
Instructed by thy arts, a power they find
To vanquish realms where once they lay confined.

The Cardiganshire mines at this period were in a very uncertain state, but they were in the hands of a mine adventurer who did not scruple to employ the most exciting means to draw attention to his speculations.

* Printed for William Phillips, at the Black Raven, Chancery Lane, London.

In 1698 arose the novel scheme of the "Mine Adventure," of which a prospectus, with the following title, was first put forth :—

"The Mine Adventure, or an expedient, First, for composing all differences between the partners of the mines late of Sir Carberry Pryse; Secondly, for establishing a new method for the management thereof, and thereby (instead of an arbitrary power over the mines and stock of all the partners in one person) settling an equal and fair constitution for every person concerned; Thirdly, for granting several charities out of the same to the poor of every county in England and Wales, without prejudice to the partners; Fourthly, for enabling the partners to employ a much greater stock therein, and consequently (in the same proportion) to advance the gain and profits thereof; Fifthly, for discharging all debts, duties, and demands chargeable upon the said mines, originally occasioned by several expensive law-suits between the said Sir Carberry Pryse and the patentees of royal mines; and, Sixthly, for raising a large stock of £20,000 (clear of all manner of incumbrances) for the working and carrying on the said mineral works to the great advantage of the King and kingdom. Proposed by Sir Humphrey Mackworth. Perused and settled by Eminent and Learned Council in the Law; and finally established in two indentures made and executed by the present partners, and which shall be enrolled in the High Court of Chancery."

Such were the high pretensions of those interested in the scheme of the "Mine Adventure." Mr. Waller, writing at the same period, in the form of a circular to the people of England, gives the most exaggerated account of the Cardiganshire mines. "This adventure," says he, "is recommended to the world as an undertaking whereby not only His Majesty's Customs and the trade and wealth of England will be advanced by the lead and copper, being commodities and manufactures of our own country, and thereby the exportation of our coin and bullion, obtained with so great difficulties from Spanish Indies, in great measure prevented."

After giving a section of the veins on the estate of Sir Carberry Pryce, he adds: "And thus you see that there are eight large veins of silver, lead, and copper ore lying near together in one mountain, where one level serves to drain the water from all or most of the said veins, and which, it is presumed, can't be paralleled in any part of the Christian world."

And, again, having set forth the advantages of the situation of these mines, it is stated: "From all which it plainly appears (by calculation) that, with a stock of £20,000 and good management, the said mines would yield a yearly profit, over and above all charges, of £171,970 19s. 9d. for lead, besides the silver, which is believed will yield, one tun with another, about £14 in silver per tun of metal, and may, in all probability, double this valuation of the mines. 'Tis plain that this nation can never want silver if these veins are carried on with a large stock, and will yield such large quantities of oar at so small an expense as is herein mentioned. This valuation may seem incredible to many persons not skilled in the art of mining, nor acquainted with the vast advantages that may be made from mineral works, especially so large and so well situated near the sea as these are. But if demonstration will not convince 'tis in vain to use any other argument." Appended to this account is a rude map of this part of Cardigan, showing the position of the mines and of the lodes. In an abstract of the accounts rendered by Mr. Waller to the company in 1700, we have some returns relative to wages and the expenses of smelting in Wales. A copy of one of these accounts is given in the accompanying note.*

* An account of the refining 72 tons 1 qr. 10 lbs. lead, at Neath, from the 16th July, 1699, to 16th March following, viz.:—

				£	s.	d.
The lead refined, 72 tons 1 qr. 10 lbs., valued at Neath at £8 per ton				576	2	8
The charge of refining said lead:	£	s.	d.			
To 120 bushels of bone ashes expended, at 4s. per bushel	24	0	0			
To 15 weigh of coals at 20s. per weigh	15	0	0			
Carried forward	39	0	0			

In the year 1700 the company was regularly formed under the title of "The Governor and Company of Mine Adventurers in England." The customs observed at this time appear to have been the same as those of the present day. It would appear, from a statement made by Mr. Waller, that they were working upon six veins of lead and two of copper. The following tabular view was drawn up by Mr. Waller :—

Name of Mines.	Nature of Ore.	Number of lodes worked up to this date.	Number of lodes known, bu[illegible] yet worked.	[illegible]f A[illegible] [illegible]vel.	Boundary of silt.	Size of the lodes.	Assay of ore. Silver per ton.
				Feet.	Miles.	Feet.	
Bwlch-yr-eshirhir	Lead / Silver			..	37	4 to 8 / 3	
Bwlch-Laninogg	Lead / Copper*			270	..	2 to 3	
Cwmsumblock	Lead / Silver			192	..	2	
Goninian	Lead / Silver			300	..	..	44
Brinpica	Lead / Silver			210	..	$1\frac{1}{2}$	44
Cwmervin	Lead / Silver			54	..	4 in. to 3	44
Pencraiddy	Lead / Silver			120	..	3 to 5	44
Ysttmuean	Lead				..	1 to 2	
Cwmystwith					..	various† / $\frac{1}{2}$ to $1\frac{1}{2}$	
New Mines					..	6 feet	

	£	s.	d.	£	s.	d.	£	s.	d.
Brought forward				39					
To wages to workmen as follows:									
Paid John Grimshaw, for 21 weeks, at 21s. 6d.	22	11							
Samuel Ackroyd, for ditto, at 16s.	16	16							
Thomas Humbledon, for ditto, at 10s.	10	10							
William Dalton, for ditto, at 9s.	9								
Thomas Forrest, for ditto, at 9s.	9								
Michael Parker, for ditto, at 8s.	8								
John Jennings, for ditto, at 8s.									
Robert Reynolds, for ditto, at 7s.									
Richard Gascoigne, for ditto, at 7s.									
				100	5	6			
To 428 casks for litharge, at 20d. each	35	13	4						
To heading ditto, and nails, 2d. per cask	2	11	4						
To seven dozen of candles expended, at 5s. per dozen	1	15	0						
To smith's work, for mending tools	1	10	4						
				41	10	0			
Whole charge of refining said lead							180	15	
The value of the lead, and charges of refining it							756	18	
The said lead refined produced 660 ounces of bullion, at 5s. 6d. per ounce				181	10	0			
And 74 tons 18 cwt. 2 qrs. 20 lbs. litharge, value at Neath at £10 per ton				749	6	9			
				930	16	9			
By the above account it appears that the bullion and the litharge produced from the said lead amounts to				930	16	9			
That the lead and charges of refining it exceeds not				756	18	2			
And consequently there gained by refining the said lead				173	18	7			

Which is £22 19s. 10d. per cent. clear profit, errors excepted.

THOMAS HORNE.

* Producing 1 in 5 of fine copper.

† Silver vein, runs in bellies of ore from 4 yards broad to 7 yards, and from 10 yards long to 31 yards, and from 4 yards high to 7 yards, then connected by leaders of an inch thick for 3 or 16 yards.

The quantity of lead raised, notwithstanding all the pretensions of those with whom the scheme originated, was never large. Mr. Waller furnished an account, of which the following is a summary:—

	£
The original stock of this company	20,000
Leased by building houses for the miners, carriage of ore, stores, and other incidental charges	5,000
Stock in litharge, lead, and silver in the merchants' hands . . .	4,000*

In 1709 disputes arose. Sir Humphrey Mackworth and Mr. Waller quarrelled, and accused each other of unfair dealings. The company discharged Mr. Waller, who petitioned the House of Commons, and a committee of inquiry was ordered. The result of this was the following:—

"Ordered, that a Bill be brought in to prevent the said Sir Humphrey Mackworth, William Sheres, and Thomas Dykes, their leaving this kingdom, and their alienating their estates until the end of the next session of Parliament, and that Mr. Benson, Mr. Arstaby, and Sir Richard How do propose and bring in the Bill."

Sir H. Mackworth published a defence of his conduct, and some of his friends published "A Vindication" as late as 1720. Numerous pamphlets and small volumes, written by shareholders and others, were issued between 1700 and 1737.†

In the library of the British Museum will be found the original manuscript account-books of this Cardiganshire Mine Adventure and some curious prospectuses issued by Waller and his partners. From these much of the information given has been derived.

From the published lists we learn there were 650 shareholders. These embrace people of every class—peers, bishops, knights, farmers, and humble shopkeepers. From the list of persons making claims of sums respectively due to them for stock, bonds, &c. &c., the names below are taken at random for the purpose of affording some idea of this extraordinary bubble scheme, which unfortunately finds some examples in our own days. Although a few

* From Mr. Waller's account we learn incidentally that litharge was never made a marketable commodity in England until Mr. Robert Lydale, the chief operator to this company, patented a process for its preparation. It was usually sold at £20 per ton, but, from these works it was sold at the price of red-lead.

† The following is a list of the various pamphlets, &c., published on "The Mine Adventure:"—

"Mine Adventure—Case of the Mine Adventure," folio; "Bill for the Relief of the Mine Adventurers," folio; "List of the Adventurers," folio, 1700; "Familiar Discourse, or a Dialogue concerning the Mine Adventure," 8vo, London, 1701; 8vo, 1705; "Proceedings of the Mine Adventurers," folio, 1704; "Rules, Orders, &c., of the Company of the Mine Adventurers," 4to, London, 1706; "Proceedings of the Company of the Mine Adventure in their transactions with Mr. D. Peck," folio, 1707; "List of the Company of Mine Adventurers," folio, 1708; "Proceedings of the General Court of the Mine Adventurers," folio, 1708; "Report of the Committee of the House of Commons relating to the Mine Adventurers," folio, London, 1710; "List of the Persons who have made a Claim upon the Company of Mine Adventurers," folio, 171[illegible] "List of the Creditors of the Company of Mine Adventurers," 4to, London, 1712; "List of the [illegible]prietors of the Company of Mine Adventurers qualified to Vote," folio, 1727; folio, 1730; "Abstracts of the Present State of the Mines of Bwlchyr Eskir Hyr," 8vo, London, 1700; "Mine Adventure, Answer to Several Objections against," 8vo, London, 1737; "Mine Adventure, Settlement of," folio; "Journal of the Mine Adventurers," Stockholm, folio, MS.; "Account of the Proceedings of the Mine Adventurers," folio; "Advantage of the New Scheme of the Mine Adventurers," folio; "Reason for and against the Bill of the Mine Adventurers," folio; "Remarks on a paper entitled 'Observations on the Bill relating to the Mine Adventurers,'" folio; "Answer to a Paper published by one Bateman against the Mine Adventure," folio; "List of the Governors and Court of Directors of the Company of the Mine Adventurers," 4to; "Case of the United Creditors of and Proprietors of the Mine Adventure," folio.

names only are given, the original list, which still exists in the British Museum, and may be referred to, is a far more extensive one:—

	£
The Right Hon. the Earl of Bolingbroke	700
Rev. Dr. Samuel Blithe	1,200
Thomas Bretton, Esq.	3,550
Mrs. Elizabeth Dillingham	1,770
The Duke of Leeds	6,440
The Hon. Colonel Nassau	1,219
Richard Sterne, Esq.	14,098

The claims of the various branches of the Mackworth family are curious:—

	£	s.
Buckley Mackworth, Esq.	2,037	14
Sir Thomas Mackworth	4,335	0
Mrs. Ann Mackworth	6,663	0
Mrs. Mary Mackworth	6,613	0
Herbert Mackworth, Esq.	6,656	0
William Mackworth, Esq.	6,510	0
Sir Humphrey Mackworth	61,740	0
Kingsmit Mackworth, Esq.	6,530	0

In 1744 the following mines only were working, and in these but few men were employed: Pencraigddu, Grogwymon, Cwm-ystwyth, and Eurglawdd. Some of the managers of the Mine Adventure retained, but did not work, Cyginan, Brin Picca, and Bwlch-cwm-Ervyn; whilst they gave up Esgain-hir, Talybont, Cwm-symlog, and others. Shortly after this a Flintshire company worked Darren, belonging to Mr. Griffith, of Pen-y-pont-pern; Ynishir, Talybont or Galth-y-Crûb, Esgair-hir, Caneinog, Bryn-Llwyd, and Cwm Sebon, belonging to Mr. T. Price.

In 1751 Mr. Lewis Morris published "A Short History of the Crown Manor of Creuthyn, in the County of Cardiganshire." We have in that a long discussion of "Mr. Powell's scheme of converting all the King's commons in Cardiganshire into freeholds in order to deprive his Majesty of his mines and other royalties in that county." In 1757, and for many years after, the above Mr. Morris derived a large income from the mines he was then working.

From this period we cannot obtain any authentic information of the progress of mining in Cardiganshire until 1810, when Sir Samuel Rush Meyrick published the following list of the mines then working:—

Cwm-symlog, yielding about 40 ounces of silver to every ton of lead.

Darren Vawr, giving 35 ounces of silver to the ton of lead, and 12½ cwt. of lead from a ton of ore.

Goginan, producing ore of a similar character, which sold at that time for £11 a ton.

Darren Vach.

Cwm Ervyn.

Llanvair.—In 1806 the ore from this mine sold for £27 per ton, containing from 60 to 80 ounces of silver to the ton of lead.

Mynydd Vach, discovered in 1798, but not then fairly worked.

Escair Vraith, producing principally copper ore, which in the year 1791 sold for £25 per ton.

Rhys Cynvelin.—Lead and copper.

Escair Hir.—In 1806 the ore sold at £18 a ton.

Allt-y-Crûb, worked by a Shrewsbury company.

Llewernog, worked by Sir Thomas Bousalt and by Mr. William Poole, producing lead ore and sulphuret of zinc.

Ystym Tuen.

Hên Bwlch.

Aur-glawdd.

Moel Góch ore sold in 1806 for £16 per ton.

Pen-y-bauch.

Nant-y-Crier.—Sulphuret of zinc and lead. Lord Powis has a grant of it from the Crown, and Mr. Sheldon held it of Lord Powis.

Gellaw Erin ore sold in 1806 for £19 per ton.

Rhûr-yr-Agos.—Sulphuret of zinc and lead.

Bron-y-Goch lead ore sold for £18 per ton.

Black Jack, for £4 10s. per ton.

Llwng Wnwch.

Grogwnion.

Log-y-Lás.—A level was begun about 1790.

Escair-y-Mwn.—In 1751 three workmen took a year's lease of Mr. Morris, and in that time cleared £1,300 each. Lord Powis has a grant of it from the Crown.

Cwm-ystwyth.

Nant-y-Meirch.—Sulphuret of zinc, which in 1806 was sold for £5 10s. per ton.

Cwm-yr-Anner ddû, Nant-y-Cagl, Pen-y-fordd Goch, and Pen-y-sarn, not worked.

Bhysgog.

Escair-gad-vach, Cwm-trinant, Tan-y-gaer, Bach-ddû, producing very small quantities of ore.

These brief notices will, it is hoped, afford a general view of the progress of mining industry in Cardiganshire up to 1810.

STAFFORDSHIRE.—The copper ore has been already described. The lead ores of this county appear to belong to this place. Plot says of the lead ores, "They cannot be said to be *earths*. Lead is dug here in a yellowish stone, with *cawk* and *spar* in *Fown's field*, belonging to one Townley, on the side of Lawton Park, where the workmen distinguish it into three sorts, viz. *round ore*, *small ore*, and *smithum*; the two last whereof are first beaten to pieces with an instrument called a *knocking-bucker*, and the ore separated from the stone with another, called a *limp*, and then washt with a seive made with iron wyre, yet further to clear it from terrestrieties, which done it is sold to the potters at Burslem from £6 to £7 a ton, who have occasion for most that is found here for glazing their pots. There has been lead ore dug also at *Ecton Hill*, where some of it lies so near the day that it was first found by the plough. Here also they distinguish it into three sorts, but under different names from the former, the best being *bing*, the middle sort *bowse*, and the lead-dust *smithum*; and there was *lead ore* dug formerly by the Right Honourable the Earl of Shrewsbury at Ribden. But none of these works were ever very considerable, nor is it likely any such should ever be found here, it being observed that wherever

there is much coal, there is so much the less lead, its sulphureous spirit being too strong for the production of that *metal*; upon which account, when near Mendip there was found two or three hundredweight of very good lead ore growing to a vein of coal, it was looked upon by all as a very great rarity."*

LANCASHIRE, YORKSHIRE, AND CHESHIRE.—A green carbonate of copper is stated to have been discovered by Mr. W. Marshall in the Magnesian Limestone at Newton Kyme, near Tadcaster. The copper runs through the Limestone in thin veins, dipping considerably to the west, which is also the dip of the Limestone itself. That copper has been of frequent occurrence in this quarry is proved by the débris and the copper-stains on stones built into the old walls about Newton Kyme. The Coniston mine, on the banks of the lake of that name, has proved a good copper mine; and this ore has been found at Merrybent, near Melsonby. These will be properly noticed in a future chapter.

At Farnham, two miles north-west of Knaresborough, in the Magnesian Limestone, copper is said to have been obtained in small masses, and a considerable quantity is said to have been formerly obtained by means of galleries worked through the Limestone. The workings were abandoned and the shafts filled up, owing to the quantity of water accumulating, which the rude engines of the time, worked by horses, could not overcome.

A small quantity was found in 1805, upon sinking a well through the Limestone at Farnham.†

Charles Leigh, Doctor of Physic, 1700: "The metals of those countries are *lead*, *iron*, *copper*; the *Metallis affinia*, or bodies betwixt metals and minerals, are *antimony*, *black lead*, and *Lapis calaminaris*. *Lead ore* is frequently found either in spars, white sand in the fissures either of limestone or freestone, and then it runs in veins, as the workmen call it. These are of different sizes, sometimes the *mine* being a quarter of a yard in diameter, and the same *mine* sometimes not above an inch, and a little after, the rock clasping together, the veins entirely disappear, through which, the miners, continuing to work, recover the vein of metal as formerly. . . . . There are four kinds of *lead ore*, viz. the *spar ore*, *coke ore*, *potter's ore*, and *white ore*. The *spar* and *coke ore* are about equal value, and are fluxed with white wood in furnaces for that purpose, and they usually run about a fourth or fifth. *Potter's ore* will not lose above a seventh, and frequently contains a portion of silver. The white ore is a natural *ceruss*, and yields a greater quantity of metal than any of the rest."‡

"Near Chorley, twenty-five miles north of Wigan, are lead mines, not now worked, belonging to Sir F. Standish. These mines, which produced the witherite, or ærated barytes, were sunk in the grit or sandstone; they ceased to be worked fifteen years since (*i.e.* 1787), and are now filled up by the earth running in, or are full of water" (*Mawe*).

"To the west of Lankester is Ulverston, remarkable for iron mines of rich hæmatites. One perpendicular vein of ore is thirty yards wide, in limestone.

* "The Natural History of Staffordshire." By Robert Plot, LL.D. 1686.

† Wm. Marshall, Esq., "Notice of Carbonate of Copper occurring in the Magnesian Limestone at Newton Kyme, near Tadcaster." ("Geological Transactions," Second Series, vol. ii. p. 140.)

‡ "Natural History of Lancashire, Cheshire, and the Peak, in Derbyshire."

Large nodules, some even weighing 4 cwt., of a kidney form, metallic lustre, and stellated fracture, are found in the loose earth" (*Mawe*).

At Alderley Edge is a very remarkable deposit in the sandstone, of copper and lead. The existence of scoriæ in the ploughed fields to which my attention was called by Lord Stanley of Alderley, proved that smelting operations had formerly been carried on here. It is stated that cobalt having been found in this sandstone, a Liverpool man established works for the production of smalts, and made much money by the process. He was eventually stopped by the authorities, who established their position, and the heavy surcharge for making glass without a licence was his ruin.

ISLE OF MAN.—Evidences of mining operations carried on at a very early date have been noticed at Brada lead mine, in the south of the Isle of Man.

John Comyn, Earl of Buchan, obtained from Edward I. a licence to dig for lead in the Calf of Man to cover eight towers of his Castle of Cruggleton, in Galloway.*

In the course of the period from the fifteenth century to the seventeenth, the family of Stanley sought for copper in the Isle of Man, and some traces of their workings can still be found. The ore discovered was not abundant, but of good quality, producing six pennyweights of copper per ounce of ore.

In the Statute Book of the Isle of Man various notices of mining operations occur under the dates A.D. 1422, 1613, 1618, 1630.

Bishop Wilson, in his "History of the Isle of Man," expresses his belief that mines have been wrought in the island from a very early period. What this means it is impossible to say. Mention is made of mines in the Isle of Man in the time of Sir Stanley, appointed King of Man, by grant from King Henry IV., in the year 1407. Mr. Fitz-Simmons says that the mines at Brada, he believes, were the first opened; whether those at Foxdale were then opened may be doubted. The Laxey mines were worked by a Cumberland company about the commencement of the eighteenth century.

Mr. William Scott, of Douglas, thinks that the mines at Brada were wrought previously to the discovery of gunpowder, from "feather wedges" having been found in the levels.

Mr. William Geneste informed Dr. Berger that he found in some book, "Charge of the Revenue," in the Seneschal office in Douglas, "that the last Earl of Derby had the mines wrought, paying the workmen at the rate of £3 Manx per ton for the lead ore raised. In the year 1709 he paid the miners for seventy tons; from the years 1709 to 1713 about thirty tons yearly. A new smelting-house was built in the year 1711. The working of the mines was totally suspended about three years ago."

SCOTLAND.—In the records of mining in this kingdom we find numerous licences, amongst others the following:—

1562.—John Acheson and John Aslowan to mine for lead.

1565.—Johnne Stewart, of Farlair and his sonn, "licence to wynt and transport all and sindry kyndes of metallick uris."

1565.—August 26th, the Earl of Athol, regarding the workes of the mines of Glengonar and Wanloch.

* "The Isle of Man." By the Rev. Joseph George Cumming, M.A. 1847.

1565.—Contract between the king and queen and several burgesses of Edinburgh for the mining of 40,000 stones of lead ore. 31st Oct. 1565.

In 1586, George Douglas, of Parkhead, had a grant of mines in the lead-hill district. He was accidentally killed by a landslip, and when his body was found "he had good store of gold above him."

1592, 8th June.—Memorial anent the metals for the laird of Merchantstonnis. This relates to sundry mines, and among others, "Item, imprimis the copper mynd in Vyndloch had he wrocht at thre quarteris of an yeir and xii. men." The second, "The leed myne in Glengoner water which he wroch at by the space of three years: sum tyme xxiii., sum tym xxx., sum tym xxxvi. men.

1153.—Henry, Archbishop of York, made complaint at Carlisle, to King David, on account of his forest, which the King's men who worked in a *Silver mine*, wasted.* This is quoted from J prior Hagustal, c. 288. Ritson states that, after David had conquered Northumberland and Cumberland, it was agreed between him and Stephen "that Northumberland should be yielded to king Stephen, and Cumberland remained to king David."

In 1620 Sir Thomas Menzies, provost of Aberdeen, went to London "with specimens of silver ore found in Sutherland, which were very rich, but as he died without disclosing what part of the shire they were found in, the mine has still to be discovered."†

Between 1710 and 1715 Sir John Erskine of Alva discovered a valuable vein of silver between Middlehill and Woodhill, in the Ochills. This was so rich that 14 ounces of ore produced 12 ounces of silver, and for a short period the proceeds of the mine were stated at £4,000 per week. In 1767 Lord Alva presented to the church of Alva a pair of communion cups on which the following inscription is engraved: "*Sacris in ecclesia S. Servani apud aleth A.D.* 1767, *ex argento indigena D.D.C..q Jacobus Erskine.*" ‡

Between 1585 and 1590, says a document from the Balcarres MSS., 15,717 stone weight of lead obtained in Lanarkshire was shipped for foreign use.

From a charge against the laird of Merchiston, it would appear that before this, a large trade was carried on from Leith.

In 1593, Thomas Foulis "had got a tack of all the mines in the sheriffdom of Lanark. In 1597 the trade from the Lanarkshire mines had much increased. Foulis died about 1611." §

In 1641 the mines in Waterhead and Glengonar were granted to Sir James Hope, of Hopetown, and in 1649 an Act of Parliament was passed to protect the lead mines and miners.

In 1661 Sir James Hope obtained a long Act, ratifying former grants. At that period not only did the family possess the original lead mines in Crawford Moor, but also the copper mines in Aithray, and the silver mines called the Binnie Mines.

In 1606 silver was discovered in considerable quantity at Hilderston, in Linlithgowshire, on the property of Sir Thomas Hamilton, of Binnie. "Sir Bevis Bulmer hath sett downe in his booke the manner how the rich silver

* "Annals of the Caledonians." Joseph Ritson. W. & D. Laing, Edinbro'. 1828.
† Sir Robert Gordon's "History of the Earldom of Sutherland."
‡ "Old Statistical Account of Scotland," vol. xii.; Nimmo's "History of Stirlingshire."
§ Irving's "Upper Ward of Lanarkshire."

mynes at Hilderstone, in Scotland, were found, and how they were lost, &c. Now concerning the finding thereof, Sir Bevis saith in his booke that it was found out by meare fortune or chance of a collier, by name Sandy Maund, a Scotsman, as he sought about the skirts of those hills neare the bourne or water of Hilderstone. And this Scotsman, by means of digging the ground, hitt upon the heavy piece of redd-mettle; no man thereabout ever saw the like. It was raced with many small stringes like unto hairs or thredds. It had descended from a vaine thereof, where it had engendered with the sparr-stone, which sparr-stone in forraine provinces is called by other travellers *Cacilla*. And he sought further into the ground, and found a piece of brownish sparr-stone, and it was mossie. He broke it with his mattocke, and it was white, and glittered like unto small white *copper-keese*" (copperas, or sulphate of iron, probably the arsenial sulphide, as recently cobalt has been discovered in this mine), "which is to be found in many common freestones. And he never dreamed of any silver to be in that stone, and he showed it to some of his friends, and they said, 'Where hadst thou it?' Quoth he, 'At the silver bourne under the hill called *Kerne-Popple*.' Whereupon a gent of Lythcoo (Linlithgow) wished Sandy Maund to travaille into the Lead Hill, and about Glangowner Water he should hear of one Sir Bevil Bulmer, and said, 'If it prove good he will be thankful, if otherwise he will reward thee, and I will send to him by letter.'" There is much more of the same uncertain character. A specimen is obtained and sent to Mr. Atkinson, of Foster Lane, London, and "he tryed and recommended it above all others that ever they saw before."

The Earl of Salisbury was consulted by Mr. Atkinson, and the Earl said: "A more curious piece of work in a stone (viz. in a menerall or minerals stone) no man hath ever seen, which I esteem above all others, because of Scotland, from whence I have had sundry times gold, but never anything of this sort as perfect silver." . . . Atkinson thus describes the mineral: "The manner how it grew was like unto the hair of a man's head, and the grass in the fields, and the vaine thereof out of which I had it was once two inches thicke, by measure and rule, the mettle thereof was both malliable and toufe. It was coarse silver, worth 4s. vi.d. the ounce weight, not fine silver, as is made by the art of man. The greatest quantity of silver that ever was gotten of 'God's Blessing'" (the name given to the mine) "was raised and fined out of the red mettle, and the purest sort thereof; this conteyned in it 24 ounces of fine silver upon every hundred weight, vallewed at vi. score pounds sterling the ton, and much of the same redd-mettle by the assay, held twelve score pounds sterling per ton weight. . . . And when I wrought on the first sorte redd mettle for Mr. Bulmer and my Lord Advocate of Scotland sundry times I refined, and commonly for the space of three days weekly I made an hundred (pounds) sterling each day, &c. Some part of the redd-mettle was brought to London to be tryed, and small profit arose thereof, and scantily it paid charges thereof, for the blessing of God was extracted by God's providence before."

Lord Menmuir (Mr. John Lindsay, of Drumcair) was promoted to the bench in 1581. He married Dame Marion Guthrie, granddaughter of Sir William of Lunen, &c.

Lead mines, supposed to be of great value, were discovered in Glenesk, and rocks of alabaster, excellent, as it was asserted, for lime; and Lord Menmuir, whose attention had already been directed to mining, with a view to the improvement of the public revenue, entered eagerly into the project of working them. Workmen were procured from Germany, smelting-furnaces built, and large sums expended; and how sanguine their first hopes were, and with what zeal the enterprise was begun at last, after several ineffectual commencements, the following letter will show. It was carried to Edzell by a German engaged by Lord Menmuir for the business:—

"RIGHT HONOURABLE SIR AND BRODER—

"Efter heartly commendations of service, please wit I have chosen ane metal-man, very metal-like, and hes sent him to you as maist necessar for mony affairs. He can burn lime, and says the grey stane at Invermark, beside the lead eur, whilk also he effirms to be lead eur, is a lime stane. He can make charcoal of peats, and will desire na other fuel, either to burn lime or melt copper. He is perfyt in kenning of ground and discovering of metals. He can essay the little essay, and melt in great, and will learn Andro Daw and all your folks. He offers for ten pounds sterling to big you a miln (build you a mill), whilk will serve for melting of copper and lead, and making of iron, whilk also he can make perfectly; and says, gif ye will get him a seam bot three fingers braid of your copper, he shall pay himself all his yearly wages, and get you two hundred pounds sterling of yearly profit, whilk will extend to mair nor nineteen hundred pounds Scots. He will promise to tarry for a year with you, providing he be thankfully payit of three pounds twelve shillings in the ouk (week), whilk is eight shillings less nor the twa Dutchmen whilk we had before, and that he be oukly (weekly) avancit. He will given you down twelve shillings of his oukly wages gif ye will furnish to himself and his wife a house and fire, whilk I think best, for it will be easy to you, and hald you in sa mickle silver oukly. He has a very guid conceit of your eur, and says Thomas Foulis' folks hes cassin (cast) away over meikle thereof, and desires na better nor (than) he hes cassin away. With these foresaid guid qualities ye mon (must) understand he hes a bee ('He has a bee in his bonnet,' Scotch proverb), as mony guid craftsmen hes, and is fickle, and gif he be not weill handlit and payit, he will slip away, as he hes done presently fra Thomas Fowlis' wark. Yet I have gotten Thomas his consent. I fear your forgetfulness in payment, and in appointing his house and fire, and in causing him be furnishit upon his awin expences, therefore divert all thir things to your carline (meaning literally 'old wife'). Farder, the Earl of Argyle has written earnestly to you to be in Glasgow the second of April next at a solemn convention of his friends, wherein ye maun not disobey his lordship's request, otherways he will think him far disappointit, now when he hes maist ado. I will (if) able keep the tryst myself. It will be but three days' riding to the compass. Sa God preserve you!

"From Edinburgh, the 9th of March [1593-4].

"Your broder at service,

"MR. JOHN LYNDESAY."

"P.S.—This Dutchman says your alabaster will be excellent white plaster. They call him Bernard Fechtenburg. He hes meikle English that your carline will understand him weill aneuch."

That same year (1592) the King created and granted Lord Menmuir, for life, the office of "Master of the Metals and Minerals" within the kingdom, "knowing the qualification," says his Majesty, "of his weile beloved Councillor, and his traveles in seeking out and discovering divers metals of great valuer within this realm, and in sending to England, Germany, and Denmark to get the perfit assay and knowledge thereof."

Lord Lindsay says: "I cannot exactly say how these speculations turned out, but papers and plans without end relating to them survive in the family repositories." *

SUTHERLAND.—"An essay of the silver mines was carried to London in 1620 by Sir Thomas Menzies, Provost of Aberdeen, and, being tried, it was found very rich in silver."

ORKNEY ISLANDS.—Mr. Ganiel, the German chemist, "hath an hundred several lead ores from the Orkney Islands."

"As to the metals contained in the bowels of this country, it is affirmed that different kinds of them are to be found in the valley of North Esk. The great-grandfather of the present proprietor of Edzell (that is, Sir David of Edzell, with whom we are now occupied) discovered a mine of iron at the wood of Dalbog. This gentleman's grandson (John L. of Edzell) found some lead ore near Invermark. The son of this latter (David, the penultimate laird) found a very rich mine of lead on the banks of the Mark, about a mile up the valley from the castle of Innermark." †

IRELAND.—Mr. John Taylor, in the "Transactions of the Geological Society of Dublin," states that when Messrs. Colpoys and O'Callaghan opened the Milltown lead mine, in the county of Clare, "the ancient workings were now completely cleared, and some rude tools discovered, such as oaken shovels and iron picks, the latter of extraordinary size and weight; also the remains of fires, which had evidently been made use of to crack and loosen the masses of calcareous spar and carbonate of lime, in which the ore of this mine is chiefly imbedded."

* "The most curious of these is a contract dated 12th October, 1602, betwixt Sir David and his eldest son on the one side, and Hans Ziegler, citizen of Nuremberg, in the country of High Germany, on the other," by which the former "sets and grants to him and his companions all the minds (mines) of gold, silver, quicksilver, copper, tin, and lead, and of all other minerals (except iron and marmor) within all the bounds of . . . . the barony of Edzell and Glenesk," with right of building houses, furnaces, cutting wood, &c., for twenty-five years, the return being "to thankfully pay and deliver, &c., the fith part of all and sundry the said metals of gold, silver, &c., whilks the said Hans, his partners, &c., shall happen to dig, holk, work, and win out of the said minds," &c. &c. Sir David further granting them "the power to big and erect towns and burghs beside the said mines, to create baillies, officears, and other members within the samyn, to hold courts, and to do justice thereintil for the space of twenty-five years."

† Edwards's "Desciption of Angus," 1678.

CHAPTER VI.

GOLD, PLUMBAGO, IRON ORE, AND SUNDRIES.—TO THE END OF THE EIGHTEENTH CENTURY.

THAT the Britons collected gold from the tin streams of Cornwall and Devon appears certain. That the tin streams were at one time rich in gold is highly probable, and if the inhabitants searched those streams for tin, they would be certain to discover the gold. Cæsar states in his "Commentaries," that one reason for his invading the Britons was, because they assisted the Gauls with their treasures, with which their country did abound. Samuel R. Meyrick* speculates on the probability that the Britons wrought at a very early date the mines in Cardiganshire for gold.

It is curious to find, again and again, reports of the discovery of gold in these islands. Sir J. Pettus, in his "Fodinæ Regales," says, "Cimboline, Prince of the Trinobantes (wherein Essex is included), who had lived much at Rome in Augustus' time, was seated at Walden in that county, and did (according to the Roman way) coin monie instead of rings, which might be from that mine which was afterwards discovered in Henry IV. his time in that countie." There is not existing any account of the discovery of such a gold mine. But Henry IV., by his letter of Mandamus (11 *May*, *Anno* 2, *Rol.* 34), commands Walter Fitz-Walter (upon information of a concealed mine of gold in Essex) to apprehend all such persons as he in his judgment thinks fit, that do conceal the said mine, and to bring them before the King and his Council, there to receive what shall be thought fit to be ordered.

CORNWALL.—Of the existence of gold in Cornwall we have the following intimation by Carew †:—"Tinners do also find little hopps of gold amongst their ore, which they keep in quills, and sell to the goldsmiths, oftentimes with very little better gain than Glaucus' exchange."

Tonkin, in a note, says: "We have not only Mr. Carew's authority, but likewise in the 'Bailiff of Blackmore,' written by one Mr. Beare, in Queen Elizabeth's time, we have an account of a gentleman that, at a wash of tin at Castle Park, by Lostwithiel, took out of the heap of tin certain glorious *corns* (which they call *rux*) which he affirmed to be pure gold, and at the same time 'shewed a gold ring made of certain gold hopps, which he had gathered among the tin corns at a wash in a stream works, together with another gold ring, each of 16s. 6d. value.'" He tells us of two pieces of

* "History and Antiquities of Cardiganshire." By Samuel Rush Meyrick. 1810.

† Carew's "Survey of Cornwall, with Notes." By Thomas Tonkin, Esq. Published by Francis, Lord De Dunstanville, 1811.

tin containing gold; that Mr. Boyd imagined that gold might be extracted from tin; that Mr. William Glynn, of Glynn, had a gold seal-ring made of gold hopps found in the river Fowey; and of one Christopher Kirkly, who was sent down in the latter end of the reign of King Charles II. to make experiments in separating gold.

Borlase mentions that in 1753 some men streaming for tin in St. Stephen's Bramel, found gold so plentifully mingled with tin that the smelter took it for mundic; but the tinners made much money from this find. Borlase also states that gold has been found in the parishes of St. Ewe, Creed, St. Stephen's, St. Mewan, Probus, Kenwyn, and other places. The largest piece he had seen was found in Creed in 1756, and weighed 15 dwts. 3 grs. Sir Christopher Hawkins notices the mixture of gold and tin in Ladock Stream Works. Several pieces have been found in Carnon Stream, at the head of Restronget Creek, in the Falmouth estuary. Several fine specimens of gold found in Cornwall are in the collection of the late John Michael Williams, at Scorrier. Gold has been found in the tin streams of Dartmoor and in the hæmatite iron ore of the Poltimore and the Bamfylde mines near North Molton, specimens having been in the collection of R. W. Fox, Esq., at Falmouth.

WALES.—Of the Ogofau gold mine Professor W. W. Smyth has given the following account: "Antiquaries have long had their attention directed to the ancient mine-workings at Gogofau, or Ogofau, near Pumpsant, Caermarthenshire. These works were undoubtedly commenced by the Romans. The remains of Roman pottery, ornaments, and a bath, affords reason, Mr. Johnes (the proprietor) considers, for presuming that there was a Roman station near this spot connected with the mines. Several gold ornaments have been discovered, and a beautifully-wrought golden necklace is now (1846) in the possession of Mrs. Johnes. The name of the parish, *Conwile Gaio*, tends also, Mr. Johnes remarks, to the conclusion, that the Romans occupied this ground, provided the interpretation given to it be correct, for Conwile Gaio is supposed to signify "the advanced post of the Romans."

"It has been a matter of surprise with those who visited the Ogofau that iron pyrites was the only ore visible, and that large heaps of apparently pure quartz, carefully broken to the size of a common nut, were alone found. The Geological Survey discovered, however, a specimen of fine gold in the quartz of one of the lodes, and thus corroborated the evidence which tended to prove that the mines were worked for gold."

The majority of the workings, extending a considerable depth for some acres across the side of the hill, are *open to day*, or worked, as usual in the early days of mining, like a quarry; and the rock through which the lodes run, a portion of the lower Silurian rocks, is in many places exposed, and exhibits beds much contorted and broken, though having a general tendency to dip northward. Here and there a sort of cave has been opened upon some of the quartz veins, and in some cases has been pushed on as a gallery, of the dimensions of the larger levels of the present day, viz. six or seven feet high, five or six feet wide, and amongst these two of the most remarkable are kept clear by Mr. Johnes, and being easily accessible, allow of close examination.

The upper surface of the hill is at this, the south-eastern extremity of the workings, deeply marked by a pinch running N.E. and S.W., similar to the excavations technically called *open-casts*, where the upper portions of the lodes were, in early times, worked away; and when it was afterwards found disadvantageous to pursue the lode in this manner, a more energetic and experienced mind must have suggested the plan of driving adit levels from the north face of the hill through the barren rock, in order to cut the lode at a greater depth than it could otherwise be reached, and the perseverance exhibited in driving 170 feet through the slate in each of the levels in question, was no doubt based on a sufficient knowledge of the continuous nature of a mineral lode.

The upper level communicates with the trench on the surface of a *rise* on the lode, and with the lower level by a passage of some few feet in length, through which it is barely possible to creep, and then by workings from which a considerable quantity of matter has been removed.

The veins, or lodes of quartz, vary many degrees in their line of direction, and dip at angles of from 28° to 80°, some to the S.E., others to the N.W., and their width varies from an inch to a foot. Mr. Smyth carefully described the character of the quartz, and gives a drawing of a rock upon which he believes the Romans reduced it to powder. He continues, "In considering the proofs of the Roman origin of these works, one of the most remarkable points is the large size of the levels, whilst we know that the galleries of mines for some centuries previous to the general application of gunpowder in blasting were made so small as to render it very painful to walk through them for an hour or two. Examples of these are frequent in the older mines of Cornwall, and still more so on the continent of Europe; nor till we go back to the time of the Romans have we anything by which we can compare the *Ogofau*, but in the extraordinary hill called *Csetate*, or fortress, at Verespatal, in Transylvania. . . . ."*

A sentence from Cicero has often been quoted to prove that the Romans imagined there was no silver in Britain; but Tacitus, in his "Life of Agricola," expressly states the occurrence both of gold and silver: "Fert Britannia aurum et argentum et alia metalla, pretium victoriæ."

The recent discovery of gold in Merionethshire will form the subject of future consideration. We, however, draw attention to the reputed discovery of gold in various parts of Scotland.

SCOTLAND.—It is the general opinion of archæologists † that the gold ornaments of the prehistoric ages were made of native metal. The first historical notice of gold occurring in this country is the grant of David I. to the Abbey of Dunfermline in 1153 of a tithe of all gold which should accrue to him from Fife and Fothrif.‡ Gilbert de Moravia is said to have discovered gold in Duriness, in Sutherlandshire, in 1245.§ The Scottish Parliament granted to the Crown, in 1424, all the gold mines in Scotland, and also all silver mines in which three-halfpennies of silver could be

* W. W. Smyth, "Note on the Gogofau or Ogofau Mine, near Pumpsant, Caermarthenshire." ("Memoirs of the Geological Survey of Great Britain," vol. i. 1846.)

† "Early Records relating to Mining in Scotland." Collected by R. W. Cochrane-Patrick, of Woodside.

‡ "Regist. de Dunfermelin," p. 16; "Haile's Annals" (1819).

§ "Genealogical History of the Earldom of Sutherland." By Sir A. Gorm. 1813.

fined out of a pound of lead. James II. granted certain lands to the Carthusians of Perth, and the charter expressly conveyed all metals of every sort.*

During the reign of James IV. the gold mines in Crawford Moor were first discovered.† In the treasurer's account for 1511, 1512, and 1513, there are numerous payments to Sir James Pettigrew for working the gold mines there. There are also sums entered as wages to Sebald Northberge, the master finer, Andrew Ireland, finer, and Gerard Essemer, the melter.‡

About 1683 some gold must have been found, as a gold medal struck to commemorate the coronation of Charles I. in Scotland bears round the edge, EX AVRO VT IN SCOTIA REPERITVR.§

From that time until very recently no considerable attempt to find gold was made in Scotland.

In 1513 John Damione, Abbot of Tungland, received a sum of money from the King to visit the mines on Crawford Moor.‖ In 1515 the Queen regent again commenced mining, and paid to the "Lord Postulate of the Yles for to pass to Crawford Moor, and there to sett workmen and mek ordinances for the gold mine." ¶ Sir Robert Sibbald and Colonel Brothwick say they "have seen pieces as big as a cherry; it is exceeding fine gold," and they name four other places where gold has been found. In 1524 ** the Albany medal was made from gold found in Crawford Moor, and much of the gold coinage of the reign of James V. was minted of native metal.†† In 1526 a lease was granted to Joachim Hochstetter, Quintin de Lawitz, Gerard Sterk, Antony de Nikets and other Germans and Dutchmen, of all the mines of gold, silver, and other metals for the space of forty-three years, which was confirmed by Parliament.‡‡ In the following year a contract was made with Hochstetter and his partners to coin gold and silver money for ten years.§§ In 1535 a commission was appointed to inquire into the working of the mines, and in 1539 miners from Lorraine were sent to Scotland to work the mines on behalf of the King. They were placed under the charge of a goldsmith, John Mossman, and it appears between 1538 and 1542, 41¼ ounces of native gold were used in making a crown for the King and 35 ounces for a crown for the Queen, 17 ounces for the King's great chain, and a belt for the Queen weighing 19½ ounces.‖‖ In 1565 John Stewart, of Tarlair, and his son William, were granted the privilege of working any mines of gold and silver not previously known, they agreeing to bring the gold to the mint at ten pounds the ounce and fine silver twenty-four shillings the ounce.

Beyond this there was a large coinage of gold bonnet-pieces, and for

* "Acts of Parliament of Scotland" (Record edition), vol. ii. p. 65.
† Lesley's "De Origine," &c., Scotorum (1675).
‡ Chambers's "Caledonia," vol. iii. p. 733.
§ Pinkerton's "Metallic History," No. 99.
‖ "History MSS. Commission." Fourth Report.
¶ Irving's "Upper Ward of Lanarkshire."
** "Numismatic Chronicle" (1877)—"Records of Coinage of Scotland," vol. i. p. 54.
†† "Record of Coinage."
‡‡ "Acts of Parliament, Scotland," vol. ii. p. 310.
§§ "Record of Coinage of Scotland," vol. i. p. 64.
‖‖ Irving's "Upper Ward of Lanarkshire," vol. i. p. 53.

special ornaments, all the gold, it appears, having been obtained from Crawford and other moors.

Some of the early coins of Mary's reign were of native gold. In 1567, Cornelius de Vois, a Dutchman, obtained a licence from the Regent Murray to work gold and silver for nineteen years in any part of Scotland. Several other grants were made, and six score hands were employed in the summer months in searching and washing, the gold found being taken to the mint at Edinburgh to be coined into twenty-pound Scots gold pieces.* On one occasion De Vois sent eight pounds of gold to the mint within thirty days. Arnold von Bronchworst worked the mines subsequently for the Regent Morton. In 1576 Abraham Potterson, a Dutchman, was licensed to work the gold, silver, and lead mines in Scotland for twelve years, except the lead mines of Glengonar and Orkney, which were granted to George Douglas and others. Potterson was to pay six ounces out of every hundred of gold and silver. The miners of Crawford Moor, of Robertmoor, and Hinderland, were prohibited from exporting any gold out of the realm.†

A grant of all the mines and minerals in the country was given, in 1583, to one Eustachius Roche, who had some political mission at the Scottish Court, to search anywhere for minerals, and to use the timber of the royal forests, certain mines belonging to the Earl of Arran being specially exempted.‡

About 1578, Bevis Bulmer, an "ingenious gentleman," was engaged by a goldsmith in Edinburgh, Thomas Foullis, to work his lead mines in Lanark. Bulmer appears to have sought zealously for the quartz veins from which the stream gold had been derived, but he was not successful. Two large nuggets are recorded to have been found by him, one weighing six ounces and the other more than five ounces, of pure gold. A piece of "sapper stone" (probably part of a quartz lode) was found at Long-Cleugh Head, weighing two pounds, from which an ounce of gold was taken. Bulmer erected a stamping-mill, and succeeded in getting much "mealy gold." He appears to have worked chiefly in Mannock Moor, Wanlock Water, in Nithsdale, in Friar's Moor, Crawford Moor, and the district of the Lead Hills.§ He is said to have been most successful in Hinderland Moor, in Ettrick Forest, which gave him large quantities of gold, "the like of it in no other place in Scotland." He presented a porringer of native Scottish gold to Queen Elizabeth, on which was engraved—

I dare not give, nor yet present,
But render part of that's thy own:
My mind and heart shall still invent
To seek out treasures yet unknown.

* "Records of Coinage of Scotland."

† Thorpe's "Collection of State Papers" (1509-1603).

‡ Irving's "Lanarkshire."

§ In addition to these we have the following:—

"Ane Memorandum left by Robert Seton, commonly designed of Mexico, anent the metals in Scotland, especially gold." He gives the names of forty places where more or less gold was found. Many of these were very doubtful.

Another Memorandum of the Minerals in Scotland, communicated to Sir Robert Sibbald, by Colonel Borthwick, 1683. (*a*) Gold is said to have been found at Dunideer, near Aberdeen; in the bogs of New Leslie, two miles from Dunideer; at Overhill, belonging to Lord Glamis; at Glenclought. (*b*) Silver mines were worked at South Farrin, at Menzies, ten miles north of Aberdeen; and another near Dishlain, eight miles from Aberdeen.

George Bowes, in 1603, received a grant of £200 to be "employed about the mines of gold in Scotland," and immediately afterwards another sum of £300 to work for certain minerals in Wanlock Water. In 1604 the Privy Council of Scotland issued a proclamation prohibiting any one from molesting or troubling Sir Bevis Bulmer in his search for metals. Numerous letters from George Bowes are published in the "Early Records of Mining in Scotland," but he can scarcely be said to have been successful, although he found gold in many places.

From Atkinson's account of the gold mines of Scotland, we learn that "Mr. Bowes, who works sundry mines on Robbart's Moor at Wanlock Head, in the reign of Elizabeth, was killed in the copper mines at Keswick.

"And he went home richly into the north country where he dwelt, (but) unfortunately, in riding to see the copper workes and mines in Cumberland, Keswick, as he was going down into the deep pitts the ladder broke, and the earth fell in upon him and so was bruised to death, and thus he lost his life, and the vaine of gold not since discovered in Scotland." (This refers to a reported vein of gold said to have been discovered by Bowes in Wanlock Head).* "Mr. Daniell Hochstetter, one of the masters of the same copper mine, was then going down after him into the ground, and fell but a little way, and hurt himself, but not unto death (yet was) he sore bruised with the fall from the same ladder (but he escaped), praised be God therefore. I wrought with him since, and he tould it me for a truth," &c.

IRELAND.—The abundance of gold ornaments and weapons found in Ireland, and which are so peculiar to this people, clearly show that considerable quantities of gold must have been obtained at an early period in their history. Sufficient evidence of this is given in the testimonies of the ancient Irish writers. Delarnes, in his "History of Caen," states that when, after the Norman conquest of the British Islands, treasure was exacted from both to the exchequer of Normandy, the tribute exacted from England was 23,730 marcs of silver, but from Ireland 400 marcs of silver and 400 ounces of gold—an enormous quantity for those times.†

Toward the close of the last century gold was accidentally found to occur, disseminated in the beds of the streams which descend from the northern flank of Croghan Kinshela, a mountain which lies on the confines of Wicklow and Wexford, and at the junction of the granite ridge with the clay-slate. It occurred in massive lumps, and in small pieces down to the minutest grain. One piece weighed 22 ounces, another 18 ounces, others 9 and 7 ounces, and so on to the smallest particles.

The total quantity of gold collected by the Government-working, in about two years, was 945 ounces, which was sold for £3,675. It has been computed that at least £10,000 was paid to the country people for gold collected, before the Government took possession of the works. This native gold was

* The editor of Atkinson's book, when printed for the Bannatyne Club (1825), says: "The story of Mr. Bowes's vein of gold is a fiction. Gold is found in the alluvial soil only of the neighbourhood of Lead Hills and Wanlock Head." Atkinson, speaking of the Scotch mines, says, "For thereby God remunerates, the asker to have, the seeker to find, the hunter to follow, till that great blessing of God be laid open, viz. God's treasure-house, even that bedd or vaine of gold or silver mine vallew'd at six thousand-thousand times the charge of the adventure and labour."

† Kane's "Industrial Resources of Ireland."

of a rich yellow colour, soft and malleable. An assay of 24 grains of it, by Mr. Weaver, gave pure gold 20·58, silver 1·43.

The localities that have yielded gold in the largest quantity are Ballinvally, Ballintemple, and Killahurler, all situated in the same valley. The gold is associated with magnetic ironstone, which is sometimes in masses of half-a-hundredweight, also in iron pyrites, brown and red hæmatite, wolfram, and manganese. Particles of native gold have also been found at Croghan Moira, at Ballycrea, and Ballynacapoque.

PRODUCE OF GOLD IN THE UNITED KINGDOM SINCE 1862.

		AURIFEROUS QUARTZ.					GOLD OBTAINED.		
		Tons.	cwt.	qrs.	lbs.		Ozs.	dwt.	grs.
	WALES.								
1862	Vigra and Clogau	789	18	0	0	Poor	732	19	0
,,	,,	13	16	1	2	Rich	4,566	1	12
1863	,,	324	7	1	14		526	18	6
1864	,,	169	0	0	0		2,321	0	0
1865	,,	1,644	14	0	0		532	1	0
1866	,,	1,159	19	0	8		213	14	22
1867	,,	3,241	4	0	25		1,520	6	21
1874	,,		—				385	0	12
1875	,,		—				548	1	2
1876	,,		—				228	18	8
1877	,,		—				139	4	13
1878	,,		—				697	12	15
1879	,,		—				447	7	21
1880	,,		—				9	19	12
1865	Cwmhesian	30	0	0	0		8	0	0
1863	Welsh Gold Co.	61	8	1	12		25	14	3
1864	,,	604	0	0	0		346	0	0
1865	,,	1,234	16	0	0		277	1	0
1864	Castel-Carn-Dochan	29	0	0	0		141	0	0
1865	,,	1,360	13	0	0		837	16	0
1866	,,	1,763	0	0	0		529	1	11
1864	Prince of Wales	20	0	0	0		65	0	0
1864	Gwynfynydd	4	10	0	0		6	0	0
1865	,,		10	2	0		9	13	0
1870	,,		—				191	0	0
	SCOTLAND.								
1868	Sutherland, Helmsdale		—				577	0	0
1869	,, ,,		—				17	17	8
	IRELAND.								
			lbs.						
1876	Wicklow		—				4	15	7
1877	,,		201				4	1	8
1879	,,		472				0	2	18
1880	,,		220 quartz not treated					—	
1880	Leinster		—				4	19	11
1881	,,	0	1	1	27	Value £18 0 0		—	

IRON.—Andrew Yarranton* says he "found out a vast quantity of Roman cinders near the wall of the city of Worcester, and within one hundred yards of such walls there was dug up one of the hearths of Roman foot-blasts, it being then firm and in order, and was seven foot deep in the earth; and by the side of the work there was found out a pot

* "England's Improvement by Sea and Land," &c. By Andrew Yarranton. (The first part was published in 1677, and the second in 1688.)

of Roman coine—to the quantity of a peck—some of which was presented to Sir Dugdale, and part thereof is in the King's closet; by all which circumstances it clearly appears that the Romans made iron in England, and as far up the river Severn as the city of Worcester, where as yet there are vast quantities remaining."

Dr. Nash* (in the absence of further evidence) strongly expressed his opinion that these were not Roman relics, but in the corrections and additions to the second volume of his "History," he relaxed a little upon the point, and stated that "In June, 1797, an underground search was made, the whole length of the Broad Street, Worcester, and about the middle of the street from the Cross, near the house of Mr. Morton, cabinet-maker, not far from the Bell Inn, was found a bed of iron cinders, which extended up Mr. Morton's yard, and probably on to the walls of the city, near which was a considerable iron foundry in the time of the Saxons, or perhaps, as some think, of the Romans. About two or three hundred yards from the city walls, up the river, is a place called Cinder Point, where a great quantity of the like scoriæ are found. The specimen I have is very rich in metal. The cinders at Mr. Morton's and the Bell Inn were found to extend about forty yards in breath; and at another place, near the Cross, opposite Mr. Wilson's, about ten yards.

"I have several times examined the stratum of iron scoriæ and clinkers at Cinder Point, on the east bank of the Severn, in a place called Pitchcroft, and find that the bed is extensive and the clinkers very rich in metal. I have no doubt that this is the place referred to by Yarranton. The stratum lies by the river side about six feet deep, beneath the alluvial soil, and was most probably the rough and half-smelted ore thrown aside in the time of the Romans, they having, it is said, only foot-blasts to smelt the ironstone.

"The supposed fort of Ostorius stood exactly opposite to the Cinder Point, at the distance of about five hundred yards, on a ridge of ground, just out of flood's way, on the same side of the river, and at all times a guard to the ironworks. A few years ago I saw a similar bed of scoriæ and clinkers in the bank of a lane between English Bicknor church and the river Wye, in Gloucestershire. This was pointed out to me by the Rev. Edward Field, then the rector of that parish, and now Bishop of Newfoundland."

Dud Dudley† states that in the beginning of the seventeenth century there were no less than 300 furnaces in blast for smelting the ores of iron *with charcoal*, the average annual make per furnace, about 13 tons per week, giving an annual production of 180,000 tons, the estimated consumption of charcoal being 144,000 tons, equivalent to 17,310,000 cubic feet of timber. There is much uncertainty as to the period when the manufacture of iron commenced in Great Britain. Mushet‡ considers it probable that the working of the tin mines of Cornwall by the Phœnicians introduced into this country a class of men skilled in all the then known metallic ores, converting them into useful products. With the invasion of

* "History of Worcestershire." By Dr. Nash.

† Dud Dudley's "Metallum Martis; or, Iron made with Pit-coale, Sea-coale," &c. London, 1665; reprinted 1851.

‡ "Papers on Iron and Steel, Practical and Experimental." By David Mushet.

England by the Danes, and their consequent establishment, much additional knowledge of the art of mining and fusing ores was attained. Large heaps of scoriæ are met with in many parts of England, with so great an accumulation of soil as to grow trees of a large size. These heaps, known as Danes' Cinders, have in recent time been reduced to the metallic state; and Dud Dudley mentions that in the year 1620 oaks were found of a large size, decayed, on the tops of large hills of cinder; and the same authority states that about the same period there were reckoned 500 forges and iron-mills for refining the crude iron and converting it into malleable bars.

These works on an average made three tons each per week, for fifty weeks, giving an annual production of 75,000 tons of bar-iron, in the manufacture of which it appears no less than 90,000 tons of charcoal would be required for the year's supply at that period. The great consumption of wood in those days appear in the fact, that the above 90,000 tons of charcoal are represented by 10,732,000 cubic feet of timber, this quantity, with that used in the blast-furnaces, amounting to 28,062,000 cubic feet; an acre of ground being supposed to yield 2,000 cubic feet of timber. At the period referred to, besides iron-works, smiths' and nailers' fires, manufactories of every sort were carried on by means of wood, even at a time when pit-coal was being exported to other countries.

The enormous consumption of wood in the manufacture of iron was a source of continued complaint. "Accordingly, in Queen Elizabeth's reign, this was so strongly felt that a petition was made to the Crown praying that 'the Bloomeries in High Furness might be abolished, on account of the quantity of wood which was being consumed in them for the use of the mines, to the great detriment of the cattle.'" *

Several Acts followed each other for protecting our forests.

In the time of King James, several patents for the manufacture of iron with pit-coal were granted, but with little success, till Dud Dudley, in 1619, succeeded in making coke pig-iron at the rate of three tons per week. Previously, in 1612, Simon Sturtevant,† and in 1613, Ravenzon,‡ made experiments in the same direction, but without success. During the Commonwealth patents were also granted, in one of which Oliver Cromwell was a partner. Again, in 1663, Dud Dudley secured his last patent, setting forth that at one time he was capable of producing seven tons of coke pig-iron each week, the furnace being twenty-seven feet square, the blast impelled by bellows, which one man could work for an hour without being much tired.

It was not, however, till the beginning of the eighteenth century that the successful application of coal, previously coked, was solved by Abraham Darby, of the Coalbrookdale Iron Works, Shropshire, giving a new and greater impetus to the iron industries of the kingdom.

The value of charcoal and coke pig-iron, and of malleable iron made therefrom, in the year 1620 and later years, will convey some general idea of the increased cost of materials and labour from time to time.

* "Guide to the Lakes." Hudson, Kendall.
† Simon Sturtevant's "Metallica," 1612.
‡ John Ravenzon's "Treatise of Metallics," 1613.

			Per Ton. £ s. d.
1620	Charcoal pig-iron	. .	6 0 0
1792	Coke pig-iron	. . .	8 10 0
1798	Coke pig-iron	. . .	10 0 0
1620	Coke pig-iron, when invented		4 0 0
1792	Melting pig-iron	. .	5 10 0
1798	Melting pig-iron	. .	7 10 0
1620	Malleable charcoal-iron	.	15 0 0
1792	do. do.	drawn into wire	23 0 0
1798	do. do.	do.	27 to 28 0 0
1620	Bar-iron with coke	. . . . .	12 0 0
1792	Bar-iron with coke	. . . . .	18 0 0
1798	Bar-iron with coke	. . . . .	22 0 0

The total production of pig-iron in the beginning of the seventeenth century, as previously stated, was about 180,000 tons per annum, of which 112,500 tons produced 75,000 tons of bar-iron, of the value of £1,125,000, the remaining 67,500 tons being converted into cast-iron guns, mortars, ship's ballast, &c., of the value of £675,000, the total value representing £1,800,000.

The prices of the following varieties of malleable iron and steel about the beginning of the last century was as follows:—Rod iron, £3 10s. per ton; hoops, £7 per ton; blistered steel, £7 to £9 per ton; tilled steel, £10 to £12 per ton; and German steel, from £25 to £28 per ton; it being remarked that the manufacturer of steel buys his iron at the rate of 20 cwts. per ton, but in selling steel he gives 120 lbs. instead of 112 lbs. to the hundred-weight, or 21 cwt. 1 qr. 20 lbs. to each ton.

SUSSEX.—"In the year 1844 Mr. Turner observed, upon a heap of *cinders*, laid ready for use by the side of the London Road, a small fragment of pottery, which on examination proved to be Roman. The scoriæ of the disused furnaces are called *cinders*, and are much employed for the repair of turnpike-roads. That they have long borne the improper name appears not only from documents of ancient date, but from the designation of many localities in the iron district, as Cinderford, Cinderhill, Cindersgill, &c.

"Mr. Turner became curious, and ascertained that the cinders had been dug up from Old Land Farm, in his own parish of Maresfield. He visited the spot, and found the workmen engaged on the undoubted remains of a Roman settlement. The place is the site of one of the innumerable fields of iron scoriæ marking the localities of the extinct furnaces and forges of the Weald. Originally the bed was six or seven acres in extent, and of a depth from two to twelve feet. A few days previous to Mr. Turner's visit, the labourers had opened a grave about twelve feet in depth, at the bottom of which was a great quantity of broken Roman pottery, evidently the remains of a funeral deposit. The superincumbent stratification was as follows: the ground had been excavated, first, through about one foot of earth, then through a layer of cinders five feet in thickness, and, lastly, through about eight or nine feet of earth. The cavity had been entirely filled up with cinders."

Previous to Mr. Turner's investigations, the digging had been carried on for many months, and two years before that time the foundations of a building, measuring, according to the statement of the workmen, about thirty feet by twelve, were uncovered; they were rudely constructed of stone, and lay about six feet beneath the surface. A human skeleton in a very perfect state was discovered at the same time, but it crumbled to dust on exposure to the air.

Several skeletons have been exhumed from the cinder-beds, in which the bodies had been interred as in ordinary soil. If these be Roman interments—which they undoubtedly are—we are led to suppose that they were made long subsequently to the original deposit of scoriæ, since a *recently formed* cinder-bed would have been a very unlikely spot to be selected for the burial of the dead. The fair inference from these considerations is, that the iron-works at this place were carried on by the Romans during a long series of years.

The remains of Roman pottery are so numerous on this spot that scarcely a barrow-load of cinders is removed but it contains several fragments; though very rarely are any vessels found entire.

Several coins have been discovered, principally the second brass, of Nero, Vespasian, and Tetricus—and a fragment, much oxidized, of one of Dioclesian. Some coins have undergone the action of fire, and cannot be identified. The coins of Vespasian are of common occurrence. Several remains of pottery, glass, pieces of sheet-lead full of nail-holes, with fragments of wood adhering, a quantity of broken bricks, and a *stilus* have been dug up.

From all evidence that has been obtained it would appear that the Romans were but imperfectly acquainted with the art of smelting ores. The most extensive ironworks carried on by the Romans in this country were those in Gloucestershire. So large were these works, and so imperfect the smelting, that in the sixteenth and following centuries the ironmasters, instead of digging for ore, resorted to the beds of scoriæ for their principal supply of metal. The scoriæ of Marefield retain a far greater proportion of metal than the cinders of other beds in the neighbourhood, and are, on that account, much more valuable for the purpose of road-making.

Roman remains have also been found at Sedlescombe and Chiddingly.

Iron was wrought by the Britons before the conquest of Julius Cæsar. They must have used iron tools to construct their chariots and the formidable scythes; and Cæsar tells us their currency was principally iron rings.

The earliest actual record of the iron-trade in the south is contained in the murage grant made by Henry III. to the town of Lewes. This grant, dated 1266, empowers the inhabitants to levy the toll of one penny on every cartload of iron, and one halfpenny on each horse-load carried through the town.

A letter, written between the years 1233–1244, to Ralph, Bishop of Chichester, by his steward, Simon de Senliz, appears to militate against the existence of the iron-trade—at least in the western part of Sussex—at that period. It relates to an order from the Bishop to one, H. de Kynarst, for the purchase of iron ("x mureas de minnto ferro, si inveniri potest sive autem, marcas de grosso, et v mureas de minnto ferro") to be procured in the neighbourhood of Gloucester, and thence conveyed to the *domus hospitis* at Winchester. This order would scarcely have been necessary, if the iron-works which—in the next century—we find within a few miles of Chichester had then been in operation. The letter was among the *Tower MSS.* No.77: now probably removed to the Record Office.

In 1290 a payment was made to Master Henry, of Lewes, for the iron-work of the tomb of Henry III. in Westminster Abbey. Some years

previously, probably the same Master Henry was employed in constructing the ironwork for the King's chamber.

Iron appears to have been smelted in St. Leonard's Forest in the reign of Edward I., the works being carried on by the Crown.

In 1300, according to Stowe, the *ferrones* or ironmongers made complaint to Elia Russell, Mayor of London, that the smiths of the Wealds brought in the iron for wheels much too short, to the great loss of the iron-trade. All the manufactured iron appears to have been brought to London by water, owing to the impassable state of the roads.

In 13th of Edward II., Peter de Walsham furnished the King with 3,000 horseshoes and 29,000 nails for his expedition against the Scots.

The house returns for the parish of Lynch, in Western Sussex, prove the existence of the iron-trade there in 1342. It also affords an early instance of metals being subject to tithes: "Item diaimen ferri ecclesiæ practictæ valet per annum decem solidi." The rector likewise received ten shillings for the tithe of iron ore.*

Mr. Lower contributes the following: "The oldest specimen of this iron manufacture is a cast-iron slab with an ornamental cross and inscription in relief which exist in Burwash Church.

"The trade continued to increase during the fifteenth century; andirons, and chimney-backs, of great taste were manufactured. The series of Sussex andirons range from the end of the fifteenth to the seventeenth century.

"There are some old banded guns of wrought-iron preserved in the Tower of London, dating as far back as the reign of Henry VI.; evidently of Sussex manufacture, where the first iron cannons cast in England were manufactured (1543).

"The manufacture of heavy ordnance caused the iron-trade to increase so rapidly that several of the Sussex families became enriched, and assumed the rank of gentry.

"About 1587 the ironmasters were in the habit of smuggling their cannon abroad, upon the discovery of which they were all summoned by the Earl of Warwick up to London, who made arrangements that only a certain number of guns should be cast, which were to be sold to such merchants 'as my lord or his deputy should name.' These commands, however, do not appear to have been much regarded.

"During the seventeenth century the iron-trade of Sussex was at its greatest prosperity. The reason of its decrease was the insufficiency of fuel, which made the iron more expensive than in districts where coal was abundant."†

PLUMBAGO.—Tradition informs us that the first discovery of the valuable deposits of plumbago in Cumberland was made by the uprooting, in a storm, of a large ash-tree, growing upon the spot where "*the grand pipe*" reached the surface, lying between Farey's and Gill Level. We have no satisfactory account of the original discovery of the Borrowdale Plumbago. The following is from Mr. Otley's work. ‡

* Dallaway's "Rape of Chichester," p. 300.

† Notes from Mr. Mark Antony Lower, M.A., F.S.A., on the iron of Sussex. See Lower's "Contribution to Literature, Historical, Antiquarian, and Metrical." John Russell Smith. London.

‡ "Account of the Black-lead Mine in Borrowdale." By W. Otley.

"The manor of Borrowdale belonged to the Abbey of Furness, which, at the dissolution of the monasteries in the reign of Henry VIII., fell to the Crown, and was granted to William Whitmore and Jonas Verdon by James I. The grant also included the 'Wad Holes and Wad, commonly called *black cawke*, of the yearly rent or value of 15s. 4d.' It was sold by William Whitmore and Jonas Verdon to Wilfrid Lawson, and others, of Borrowdale, with a reservation, 'Except the wad-holes and wad, commonly called black-cawke, within the commons of Seatoller, or elsewhere within the commons and wastes of the said manor.' On account of this reservation the wad, or black-lead mine, has ever since been held separate from the other royalties of the manor. In 1876 half of it was held by shareholders and the other half belonged to Henry Banks, Esq., M.P.

"The mine has been opened in different places where the wad has probably appeared at the surface. It has only been worked at intervals, and when a sufficient quantity was procured to answer the demands for a few years, the mine was carefully closed up till that stock was reduced.

"On opening one of the old workings in 1769, it was found to have been carried to a great extent without the help of gunpowder; and this vein being pursued to the depth of one hundred yards and upwards, much inconvenience was experienced in working it; to obviate which, in the year 1798, an adit, or level, was begun in the side of the hill, which, at the length of two hundred yards, communicated with the bottom of the old workings. Through this level the water passes off, and the produce is brought out to be dressed, and on its mouth a house is built, where, when the mine is open the overseer dwells, and the workmen are undressed and examined as they pass to and from work.

"This mountain consists principally of that kind of rock called grey-wacké. A stratum of a darker-coloured stone runs through it, containing more iron, the joints strongly tinged with oxide of iron. This is traversed in various directions by strings, or small veins, exhibiting traces of wad, and it is generally at the intersection of two of these veins that the valuable bellies are met with, in one of which, opened in 1803, upwards of 500 casks of the best quality were procured, containing about one hundredweight and a quarter each, besides a greater quantity of an inferior sort. Since that time two of these bellies have been met with, which have produced about 100 casks each.

"It comes from the mine in various pieces of an irregular shape, and of various sizes, some weighing a few pounds, but the greater quantity in smaller pieces. It requires no smelting or refining; the pieces are only cleared from any stony or extraneous matter which may adhere to them, and assorted according to the different fineness and sizes.

"An Act was passed 25th George II. cap. 10, by which an unlawful entering of any mine, or wad-hole, or wad, or black-cawke, commonly called black-lead, or unlawfully taking or carrying away any wad, &c. from thence, as also the buying or receiving the same, knowing it to be unlawfully taken, is made felony. In the preamble of this Act, wad is stated to be necessary for divers useful purposes, and more particularly in the casting of bomb-shells, round shot, and cannon-balls."

The specific gravity of the best wad is to that of water as two to one nearly; the coarser is heavier, as it contains more stony matter.*

Blacklead is incapable of fusion, and was formerly thought to be incombustible, but it is found to be a carburet of iron, in the proportion of about nine parts carbon to one of iron, and being heated in a crucible with nitre, or other substances affording a great quantity of oxygen, its texture is weakened, and it is finally decomposed, the carbon disappearing and a little ochreous matter being left behind. By keeping it some time immersed in melted sulphur, the blacklead becomes impregnated with sulphur, and being first reduced into slices of about one-twentieth of an inch in thickness (the proper size for pencils), it may be thus brought to the degree of hardness required. Pencils treated in this way may be known by the sulphureous odour and phosphorescent light emitted on rubbing the point upon a moderately heated iron.

"By an account drawn up in 1804, the stock then on hand was valued at £54,000, and the annual consumption about £3,500; the best blacklead was then sold at 35s. per pound. Since that time the price has been from 30s. to 45s. per pound, and no doubt the consumption has greatly increased; and this mine, which 200 years ago was valued at 15s. 4d., has lately, on assessing the property-tax, been estimated at £2,700 a year."

Hutchinson† writes: "There are two workings; the lower one is about 340 yards above the level of the sea, the upper one about 390 yards; the perpendicular depth of the lower is about 105 yards, and of the upper between 20 and 30 yards. There are no certain marks on the surface to direct the miner to the mineral. The strata of the mountains are very irregular and broken, and the blacklead probably was formed in the fissures of the rocks. There is no regular stratum of this mineral; it is met with in lumps and irregular masses. The miners generally work through a quantity of earth mixed with stones of various kinds, then a species of hard grey granite, and after that a dark-blue stone of a softer nature, where they sometimes meet with it. Quartz and crystals are found in the workings. The rock adjoining to this mineral is sometimes tinged as black as the mineral itself, to the depth of two or three feet. The best sort is now valued at three guineas a pound.

* The following are the most reliable analyses:—

SCHRÄDER* gives the following—

Carbon	82·25
Iron protoxide	5·80
Silica	3·50
Alumina	2·30
Oxide of titanium	3·15
	100·00

VANUXEM†—

Carbon	83·37
Water	1·23

Residue by incineration, colour yellowish brick-red.	10·4	Silex	5·10
		Alumina	1·00
		Oxides of iron and manganese	3·60
		Loss	
			100·00

Dr. PERCY analysed a sample for Mr. Salmon, which gave—

Carbon	86·69
Ash	11·17
Water	2·14
	100·00

* Bristow's "Glossary of Mineralogy."
† "Philosophical Magazine," vol. lxviii. p. 161.

† Hutchinson's "History of Cumberland," vol. ii. p. 212. 1794.

"October, 1792. The wad mines were very unsuccessful for some years past; but in the last year they met with blacklead again in a pretty large quantity, but of the inferior quality, of which, in a short time, the miner procured about five tons. The mineral is described as lying in the mine in form resembling a tree. It hath a body, or root, and veins or branches fly from it in different directions; the root, or body, is the finest blacklead, and the branches at the extremity the worst the further they fly. The veins, or branches, sometimes shoot out to the surface of the ground. It is sometimes found in slops, or floats, in a body without branches. A blue rock lies on each side of the mineral, and sometimes there is a wet sludge between the rock and the blacklead. The metal in the low mine lies in two veins, one crossing the other; where they cross is the main body, and the best blacklead; and these veins fall perpendicularly for sixty fathoms in depth, the blue rocks on each side. At the end of sixty fathoms they found the end of the cross vein, and a large sop of the mineral, which came out as if it had been in a wrought basin, the form of the rock and of the blacklead were so equal."

There is a vein of plumbago which has been slightly worked occurring in the Bannerdale Lode. Hardly any good plumbago has been found in this vein; most of that which was obtained was of the grate-polishing quality. This vein runs east and west.

Mr. G. F. Crosthwaite, of Keswick,* states: "The mine has eight stages, thirty veins, eight pipes, and four great sops or bunches of wad, or plumbago, as it is usually called. In *Winkles pipe*, at the meeting of the veins, a sop was discovered in 1812, which produced 87 casks of best lead for pencils, and 495 casks of coarse lead, in all 582. The 87 casks of best lead alone would realise £24,360. The grand pipe, which was the one discovered by the uprooting of an ash-tree, was wrought to the depth of 64 yards to the top of Harrison's pipe. In 1778 no fewer than 417 casks, containing about 70 lbs. each, of the best quality, were extracted; this at 30s. per lb. would amount to £43,785. There were besides two other openings of this pipe in the ten years ending 1788. In 1802-3 Dixon's pipe was discovered, when ore to the value of £98,742 was got. So valuable a mine needed more than ordinary protection. Consequently an Act of Parliament was passed enacting that any one breaking into the mine, or picking wad or black-cawke at the rubbish-heaps would be guilty of felony. Notwithstanding, some blacklead did find its way to Keswick, and Jews came regularly to the George Hotel to buy it. The owners had all the mineral taken to London, and monthly sales were held at their warehouse only. Thus any sold privately in the country must have been got dishonestly, except scattered pieces, which were not unfrequently found in the beds of the streams washed down by the floods. Great care was taken to guard the mine. A house was built over the entrance and guards slept there with firearms. When the ore was taken to London in the six-horse waggon then used by carriers, half-a-dozen men, armed with blunderbusses, slept in the warehouse with the precious load, and guarded it on its way as far as Kendal. The present worthy steward of the mine is the

* "Old Borrowdale." Communicated to the Cumberland Associations, June, 1875.

fourth of the name who has held the office with great reputation for integrity and ability. His great-grandfather, Thomas Dixon, came from Langdale one hundred and fifty years ago, and his descendants have continued in office till the present time. The mine is now being reopened, and it is hoped that it will be a profitable undertaking for all concerned. This is the only plumbago which can be made into pencils to stand a point in its natural state, and is the purest and best in the world." Elsewhere Mr. Crosthwaite tells us, "The plumbago mines were wrought in the reign of Elizabeth by some of the German miners, who also wrought the copper mines in Newlands."

Since this was written the author has been favoured with the loan of a remarkable report, made by Farey, the full title of which is below.*

"The preliminary, or First Report, which I (John Farey) had the honour to make and deliver to Mr. Bankes, on the 17th September, 1818, in a small quarto, sewed in a paper cover, is said to contain several inaccuracies, which are to be corrected in this second report. This report is divided into seven parts, in which the underground and surface workings are all described, and an account given of the *pipes, sops of wad, glazes of wad, and sludge.*"

Five old plans and sections are then enumerated.

The sketch, by Mr. Harrison, in September, 1789.

The plan, without a name or date, sent to Mr. Bankes in the spring of 1792.

A plan, by Joseph Saint, in 1796 (said to be very confused).

Two plans, planned in 1794 by J. Foulkes, from diallings and measurements taken in 1778 and 1791, by Thomas Temperley and Thomas Kent. In these the *old men's workings* are especially referred to, but we gather no information as to the date of these workings.

Very elaborate descriptions of the workings, old and new, are given, and the diallings are most clearly and cautiously laid down. One point especially calls for attention. All the plans and sections are drawn with especial reference to the magnetic north, and the variation of the needle is given to the day upon which each plan was constructed. Mine surveyors should profit by this.

Farey advises that no further surface workings should be undertaken, and in giving his reasons for this, he describes conditions which give a good general idea of the old workings. He writes as follows: "The three instances of *sops of wad* actually reaching up to the surface of the rock, and

* A second Report, accompanied by four large Maps, Plans, and Sections (rolled in a tin case), and containing herein particular PLANS and SECTIONS, Lists, Statements, and Descriptions of all the workings of the

WAD MINE,

or Mine of Graphite, Plumbago, or Black Lead, situate on the N.W. of the village of Seathwaite, in the Manour of Borrowdale (of which Manour a general map is included), in the Parish of CROSSTHWAITE, in the County of CUMBERLAND. Belonging to HENRY BANKES, Esq., of Kingston Hall, Dorset, and at present occupied by himself and others as a Company of Lessees, under a Lease from him which expires July, 1860.

Accompanied also by a Supplement and Index to the *Book of Directions*, which was delivered to the resident Agent on the spot, in January, 1820, as to the future conduct of the several Departments of the business of the mine, and a series of *Trial Drifts* and Risings, which are recommended to be successively undertaken in search of new SOPS of WAD.

By Mr. JOHN FAREY, Sen.,
Mineral Surveyor and Engineer,
Rowland Street, London.

31st October, 1821.

A manuscript book of 210 pages, with Maps, Plans, and numerous Sections.

the recent circumstances of the *wad* in *Grisdale's pipe* having reached within sixteen yards of the surface, would still seem to justify an expectation that other valuable sops might yet be discovered by surface trials; but, considering how extensive a search the miners of early times made, when the *flushing*, or washing away of the alluvia or surface soil that took place in order effectually to examine the rock, whereof the *Seven Gills* are a memorial, considering also the large space trenched or dug and turned over quite down to the rock in search of lumps of *flobe wad*, as is recorded; these, and the dangers and difficulties which would attend fresh discoveries of wad on the surface, all concur in showing the propriety of the opinion and advice. . . . that no further open surface trials ought to be undertaken."

These surface trials were no doubt made by the Germans, and with this feeling a large fissure has been called the *German's Vein*. It is not easy to admit the existence of a real mineral vein in any part of the workings of this mine. The irregularity of the deposits, producing "pipes" and "sops of wad," and "small sops," and "bullets of wad," preclude the idea of anything approaching to the regularity of a fissure vein, although the miners have invariably used that term. In 1769 a very large "sop" was discovered, "but the number of casks which were anciently got therefrom cannot now be ascertained."

"The *Old Men's Third Sop* was by far the largest one which has been found. The date of its discovery was too far back to have been preserved, but it is believed to have been the third sop discovered, and it continued in occasional work until the year 1750.

"Wickersley's Sop was discovered in 1769, behind a rider or partition of vein stuff. This produced '177 casks of that denominated *best wad*.' The *coarse wad*, which probably would have amounted to 223 casks, was, with its vein stuff, stowed away on or behind 'bunnings' in the grand pipe, and on the next opening of the mine in 1778 the whole of this was ground down to coarse powder and thrown away into the stream."

In 1778 a sop, called the *Great Opening* Sop, was discovered. "The quantity sent away from this sop to London was 417 casks; besides great quantities were pilfed." A statement is made in a note by Farey that several men "sold wad creditably asserted to have been stolen, to the amount of £300." Several men were searched, and they "were all found with wad concealed upon them when leaving work." The mine was closed in September, 1788, and remained so until 1800. The further consideration, therefore, of this remarkable mine, which has been occasionally worked up to 1876, is postponed to a future page.

MANGANESE.—According to Lysons, manganese was first raised in Devonshire about the year 1770, at Upton Pyne, near Exeter; the ore from which, with two other mines of less consequence, at Newton Saint Cyres, is said to have supplied the whole county.

At Doddescombleigh, at Ashton, at Christow, and other places in that neighbourhood this mineral has been worked.

In 1815 the mines in the neighbourhood of Launceston and Tavistock were discovered and worked. The return of the production of Manganese has been in 1880, 2,839 tons, and in 1881, 2,884 tons.

DERBYSHIRE produces annually—from about six mines—a few small parcels of manganese.

WALES produced from Nant Uchef, in 1881, 300 tons.

WARWICKSHIRE.—Manganese was first obtained in Warwickshire at Hartshill, on the estate of T. L. Ludford, Esq., of Ainsley Hall, about two miles from Atherstone. A man of the name of Hankinson has since found this mineral in his land, which adjoins Ainsley, and raised a considerable quantity. A man called Davis has also raised some, and sold it at a good price to the bleachers in Lancashire. The soil in the neighbourhood is chiefly a red clay, and the manganese usually occurs in *detached pieces*, distributed through the clay, from one to eight feet below the surface, weighing from one pound to fifty or sixty pounds each.

IRELAND.—From Glandore the following quantities have been obtained:—

1877	50 tons.
1878	50 ,,
1879	40 ,,
1880	100 ,,
1881	250 ,,

ANTIMONY.—The production of antimony has been small in Cornwall—from 20 to 30 tons per annum. In the three years from 1778 Cornwall produced 120 tons. The mine at Endelion produced as follows :—

Wheal Boys.	*Endelion*—in	1774	19 0	at £13 0	per ton
,,	,,	1775	40 0	,, £13 10	,,
,,	,,	1776	36 0	,, £14 14	,,
			95 0		

The expense of getting this antimony, exclusive of driving an adit to the mine, has been less than one-third the amount of its produce.

Twenty-five tons of antimony was obtained from a mine at Saltash, belonging to Mr. Thomas Reed and partners. Antimony has also been raised in St. Austell parish—at Howton in St. Stephen's—and in a place called by Dr. Woodward, Barbary, and in St. Kew parish.

SOMERSET (N.W. quarter).—Only a few specimens.

DEVONSHIRE.—A few tons only have been raised in this county.

COBALT.—Mr. Beauchamp, of Pengreep, in Cornwall, in driving an adit through some part of his estate in Gwennap, discovered a lode of three feet breadth, which contained a branch of "real cobalt." It did not hold in depth, and was soon abandoned. The Society of Arts, in 1754, gave Mr. Beauchamp their premium of thirty guineas for the best cobalt then discovered in England.

At *Wheal Trugo*, near St. Columb, in a copper mine, a small vein of cobalt was found from four to six inches wide; it was *estimated* as worth £60 per ton, but little was, however, sold.

Dolcoath mine produced a small quantity of this mineral. *Dudnance*, in Illogan, yielded a little very good cobalt. *Pons-a-Nooth*, Perran-Arwothal, was worked for cobalt and nickel, for a year or two, and then abandoned.

Wheal Sparnon, near Redruth, produced much cobalt about the years 1815–17. This was of a high character.

Hawke's Point copper mine, in Lelant, near St. Ives, has been found to produce arsenical pyrites, which contains both cobalt and nickel.

The *Wherry* mines, near Penzance, produced some cobalt, and it is said to have been manufactured at Newlyn into smalts.

Cobalt ore was found at Alderley Edge, in Cheshire, and a manufacture of smalts was carried on for some years, but ultimately abandoned.

BISMUTH.—When in 1754 they found cobalt in the lands of Francis Beauchamp, Esq., in Gwennap, bismuth was discovered associated with it. Borlase says: "This bismuth was quite thrown away till the learned and sagacious Dr. J. Albert Schlosser, F.R.S., came to view it, September 8th, 1755, who extracted the cobalt tint for glass and smalts, and preserved the bismuth. We call bismuth 'tin glass.'"

I have received, when resident at Falmouth, large lumps of bismuth, said to have been collected from the waste-heaps at Dolcoath mine. I obtained from a Mr. Curnow a lump of bismuth, which he found in a stream flowing down a valley about two miles west of Penzance, near a "Jews' house," several feet under accumulations of peat.

This metal has also been found in St. Just and at St. Ives.

MOLYBDENA, Borlase says, was found "at a work in Camborne called Huel Crofty." I have seen fine specimens of molybdena found on the waste-heaps of the United mines in Gwennap.

URANIUM.—The only mine in Cornwall which, until within the last few years, was known to contain the oxide of uranium was that called Carharrack, which was situated about two miles nearly south of St. Die (St. Day). Mr. W. Phillips thus describes some specimens: "The crystals on a specimen from that mine in my possession are tabular, of a green colour, and transparent, except such of them as are partially or wholly coated by a deposition of an ochreus substance similar to that termed *gossan* by the miner. . . . . On many of the crystals have been deposited numerous minute cubes of a light green colour, which, as there is a considerable deposition of cubic arsenical iron in a cavity of the same specimen, I consider to be that substance rather than the oxide of uranium."*

In 1805 Mr. Phillips found oxide of uranium on the refuse-heaps of *Tin Croft* mine, near Camborne. The crystals were found for the most part well defined, and some of them are accompanied by *black pecherz* (the uran. oxyanté of Hauy). These were found at about 90 fathoms from the surface in a copper vein.

Mr. Phillips also obtained beautiful and well-defined crystals from *Tolcarn* mine, about two miles north of Carharrack. The veins in *Tolcarn* afforded little or no copper. The uranium was found in one of them at about 30 fathoms from the surface.

In *Wheal Jewel* specimens of red oxide of copper were covered with numerous minute tabular crystals of the oxide of uranium of a light green colour; and a specimen from *Stenna-Gwyn*, near St. Austell, *Wavelite*, has

* "On the Oxide of Uranium." By William Phillips. ("Transactions of the Geological Society," vol. iii 1816.

deposited upon it crystals of the oxide of uranium of a light yellow colour. But by far the finest specimens of this mineral were found at *Gunnis Lake* copper mine in 1811-12, near Calstock, many of them more than half an inch in diameter.

Within late years pitchblende (*uranium protoperoxide*) has been obtained from Wheal Edward and Botallack, St. Just, Wheal Trenwith, Wheal Providence, Wheal Basset, Wheal Balen, Tolcarne, Pednandrea (*mamillary*), Roskrow, United Ponsanooth, and a few other mines. The little that has been obtained found purchasers at about £26 4s. 4d. per ton.

STRONTIAN.—Masses of sulphate of strontian have frequently been found in the New Red Sandstone of the counties of Gloucestershire and Somersetshire. Near Wickwar, Charfield Green, and the northern brow of Tortworth Hill, where a small patch of the New Red clay marl covers the line of Calcareous Conglomerate that surrounds that hill, beautiful samples of this mineral have been found. They are discovered also in the Keeper's Ridge, in which also exists a bed of fine white granularly-foliated gypsum. The general distribution of sulphate of strontian in this part of the kingdom is remarkable. Near Bristol it has been found at Pyle Hill in the Carboniferous Limestone. At Cromhall, Mr. Weaver observed it in the Slate-Clay of the Coal formation. It occurs plentifully in the Calcareous Conglomerate, the Magnesian Limestone, and the New Red clay marl. In the Lias Limestone it is found in the Aust Passage, Clifton, and also on the Somerset coast near Watchet and at Berkeley. In the whole succession of formations, from the transition beds up to the Lias Limestone, strontian is found. It appears to be wanting only in the Old Red Sandstone. In Yorkshire, strontian is found at Scotton Moor, and on the Nidd near Knaresborough. In Glamorganshire, South Wales, it occurs on Barry Island, eight miles from Cowbridge. Strontian derives its ordinary name from the well-known district in Scotland. It is also found in Carlton Hill, Edinburgh; at Elgin; and pale-blue specimens of *Celestine* (from *Cœlestis*, sky-blue) at Haddington, and near Inverness.

* "Geological Observations in Part of Gloucester and Somersetshire." By Thomas Weaver. ("Transactions of the Geological Society," Second Series, vol. i. p. 317.)

BRITISH MINING.

BOOK II.

ON THE FORMATION OF METALLIFEROUS DEPOSITS.

CONTENTS OF BOOK II.

BRITISH MINING.

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ON THE FORMATION OF METALLIFEROUS DEPOSITS.

CHAPTER I.

THE ROCKS OF MINING DISTRICTS AND THE DISTRIBUTION OF METALLIFEROUS DEPOSITS.

THE distribution of metalliferous ore deposits over the surface of the British Islands claims our close attention. These deposits appear to be scattered irregularly, sometimes in rocks of one age, sometimes in those of another. Not unfrequently they are found distributed in strata differing not only in geological age, but in physical condition and also in chemical composition. From these circumstances it has too often been assumed that there is no rule upon which reliance can be placed, by which the miner may be guided in his search for mineral treasures. The uneducated toiler after subterranean wealth, following without examination in the footsteps of his fathers, satisfies himself with industriously digging into the earth, rather pleased than otherwise with the phrase, "It is only *by cutting the ground that the metal is found;*" thus admitting his ignorance of the operation of any law; the miner sagaciously declaring of any metallic ore, that "*where it is, there it is.*" The consequence of this is, that actual mining gives us but little evidence, over long periods of time, of any practical advance. The miner, notwithstanding the solitary nature of his labour, is by his training a good observer. His often anxious search for the indications of the mineral for which he delves leads him to observe minute peculiarities, which would, if recorded, be of really considerable value, and form eventually a system by which the miner's younger brethren might be guided. But it is a rule with the untrained mind to treasure every truth as a mystery, to be carefully guarded for individual use only. Experience has often well stored an individual mind with valuable facts, but these are rarely recorded. The miner trusts to his memory, and when he dies, all the results of a long experience die with him. The son has to begin where the father began, and this is repeated from generation to generation: consequently there has been no advance. A better system is happily beginning to prevail. Several attempts have been made to give the more intelligent of the young miners instruction

in those branches of science which have a direct bearing upon the varied operations in which they are engaged. In Cornwall, the late Sir Charles Lemon established, and supported for some years, a mining school at Truro, but that was eventually abandoned, the experiment not being successful. The author of this volume thought that the cause of this failure could be traced to the fact that the miner could not afford to visit the school in Truro. He therefore, in 1858, proposed that classes should be formed in the mining centres themselves, and that trained teachers should regularly visit these, and give the required instruction to the miners, in their hours of rest, and in immediate proximity to their homes. The experiment was commenced by a public meeting held on October 26th, 1859. Classes were organised in all parts of Cornwall and in Western Devon, and on the 1st February, 1861, the first general meeting was held. In some districts the classes have been well attended; in others they have worked well for a season, and then they have been allowed to die out. A great many of the students who attended the "Miners' Association," however, distinguished themselves, and are filling important positions at home and abroad. The subject of scientific instruction will form matter for serious consideration in the last division of this volume.

It must be admitted that the process of introducing a system by which observed phenomena connected with the physics and chemistry of rock formation, and of the depositions of metalliferous ores, is slowly making satisfactory way. The establishment of the "Mining Institute" in Cornwall is of good omen. Mining agents are induced to read papers on technical subjects, and these, being brought forward, are carefully discussed by the members at the meetings. Technical instruction in schools and colleges is also producing promising results. The advantages of those attempts belong properly to the consideration of the mining of the future.

With these remarks, let us advance to our legitimate inquiry. Are there any natural conditions known to be in operation in the Earth's crust to which we can trace the phenomena of mineral deposits? Can such phenomena be used in guiding the miner to the discovery of productive ore deposits?

If we examine the maps of the Geological Survey on which the mineral veins are marked, it will be seen that the ores of the useful metals are generally gathered into groups in special districts. Cornwall and Western Devon, forming one of the most important of our mining regions, demands our first consideration. A few miles westward from Exeter we reach the first group of metalliferous mines. The lead mines known as Frank Mills, the Wheal* Exmouth, and a few others, are here gathered together. As is not uncommon, in each of the mines named, the deeper portions of the veins passed from lead into iron, in the form of spathose iron ore. In the Teign Valley a large deposit of barytes has been found. Similar conditions prevail with the lead and barytes mines of the Northern English counties.

* Throughout this volume the term "Wheal" will be used. In the "Mineral Statistics of the United Kingdom" I have constantly employed, since 1847, the term "Huel," which is undoubtedly the ancient Cornish term—signifying a mine or mineral work—but the corruption "Wheal" is so undeviatingly used by all, that there is no reason why I should any longer endeavour to bring the older term into use again.

Lead ore has also been found in North Devon, in the neighbourhood of Ilfracombe and of Combe Martin.

A few miles westward of the Exmouth lead district, "lodes" (the term used in Western England for mineral veins) of several kinds of iron ore are found, especially near Ilsington; and close to Ashburton are some large deposits of ochre and umber. In the immediate neighbourhood of Buckfastleigh valuable deposits of copper ore have been discovered, and at one place rather extensively worked. Advancing still westward to the neighbourhood of Plympton, we have the Old Bottle Hill and other tin mines,—producing also small quantities of copper ore, in the neighbourhood of Hemerdon Ball,—but these are not now worked, except for the arsenical pyrites at Wheal Mary Hutchings, from which considerable quantities of arsenic are being sublimed.

As already stated, manganese has been found and worked on the eastern side of Dartmoor, and similar deposits have been discovered from time to time on the western borders, especially in the neighbourhood of Milton Abbot and Launceston. On the banks of the Tavy several mines of good argentiferous galena have been explored, and in the neighbourhood of Tavistock there have existed some of the most remarkable veins of copper ore which have ever been found. The district extending from Tavistock westward to the Tamar may be regarded as a rich copper-bearing locality, and this peculiarity extends on the western side of the river as far as Hingston Downs. Those mines in nearly all cases yield also a small quantity of tin. A peculiar tract of country in the neighbourhood of Harrowbarrow has been remarkable for mines which have produced considerable quantities of silver ore; and at Wheal Duchy, near Callington, a course of silver ore worth £200 a fathom was found, and Wheal Brothers in the same locality gave at one time great promise as a silver mine. Some few mines in Mid Cornwall and in the western district have also produced silver ores. At Crinnis *Fahlerz* was found, and small quantities of silver ore are now (1882) being raised. At Herland mine, in Gwinnear, several thousand pounds' worth of argentiferous ores were obtained about half a century since. Dolcoath at one time gave promise of being rich in silver, but the deposits have only produced about two thousand pounds' worth, and no more silver ore of any consequence has been discovered.

In the neighbourhood of Liskeard, in the parish of Menheniot, some important lead mines have been productive, and there is every probability that explorations now in progress will prove to be further successful. The copper mines on and around the Caradon Hills have been very rich and enduring. In the Granite masses near the Cheesewring many productive tin mines have been discovered. The moors extending from Bodmin to St. Austell have yielded large quantities of tin from the alluvial deposits, and some important tin mines have also been worked in the district. An extension of the peculiarities of the St. Austell district is found stretching away westward, but the deposits have proved generally poor, and there are many unproductive spots. The lead-producing district of St. Newlyn East—in which we find the important mines of East Wheal Rose, of Old Shepherds, and Cargol—appears to extend with but little variation to the Chiverton parish and its neighbourhood, where some valuable lead mines have been worked. These

may be traced on to the great iron lode in Perranzabula, where, in connection with, but beneath the spathose and brown iron ore, large deposits of zinc ore have been worked, and several strings of silver lead ore with some native silver discovered. The parish of St. Agnes has been especially rich in tin mines, and indeed all the cliffs around that parish and on to Perranzabula afford striking examples of ancient tin workings. The Great St. George mine and others near Perran-Porth have proved productive of copper, and at Wheal Prudence copper lodes may, at low water, still be observed running out under the sea.

All the country from St. Agnes to Redruth, and onwards to Camborne, has proved peculiarly rich in mineral deposits. In this and in the Gwennap district mining has been carried on more extensively than in any other part of the United Kingdom, and it may be distinguished as the most highly mineralised tract of country in these islands. In these mines tin, copper zinc ore, blende (or the Black Jack of the Cornish miners), and pyrites have been found in vast abundance. Wolfram has also been worked, and the rarer minerals, cobalt, nickel, molybdena, &c., found.

Extending from this important piece of country towards the south, we have a remarkable series of tin mines, some of them, especially the Wheal Vor series, being the richest ever discovered. Copper ore has also been found, and in the mines near the south coast, Wheal Rose and Wheal Penrose have given lead ores very rich in silver. The latter mine, especially, has been productive, according to the tradition of two centuries, of very argentiferous lead ore. On the coast, advancing towards Marazion, some rich deposits of copper have been worked. Near Penzance, in the parishes of Madron and Sancreed, large tin mines have long existed. Indeed, Ding Dong tin mine is probably one of the oldest mines to be found in this country—possibly in Europe.

The St. Just district, rich in its copper and tin mines, is distinguished by many peculiarities, which will form the subject of future consideration.

Such is an outline sketch of the great mining district of Western England, and before we leave it, it is important that we should institute a careful examination of some of the natural phenomena developed by the mining explorations of the district.

We find that the prevailing rocks from Dartmoor to St. Just (the Land's End) are Granite and Killas, or Clay-Slate, with here and there masses of Greenstone and frequently veins of Elvan.

Although mineral deposits will be found in all those rocks, and sometimes disseminated through them, yet, as a rule, the most productive portions of the lodes will be found near the junctions of two dissimilar rocks. The Granite hill of Carn Brea, surrounded by a wide area of Clay-Slate, is a striking example of these conditions. On this hill and around it—near the junction of these rocks—are some of the most valuable of our mines; and as we extend our examination away from the lines of junction, the mines become less frequent, and they certainly are less productive of metalliferous ores.

It may therefore be taken as an established fact, that, in Cornwall and Devonshire, *the junction of dissimilar rocks has a tendency to produce a richer*

deposit of metalliferous ores than are found in the same rocks at a distance from he junction.

To understand, or even to make an approach to any knowledge of the conditions under which lodes or veins are formed, it is necessary that the structure of our rock formations should be studied. If we examine with attention a geological map, made from a careful survey of the British Isles, we cannot but observe a marked distinction between the rocks which occur in the eastern counties, and those which distinguish the midland and western districts of England and the whole of Wales. From Redcar, in the north-west, we see peculiar layers of rock passing irregularly in a direction, nearly southward, to Grantham, and then, with a western deviation, striking towards Gloucester and the mouth of the Severn. These rocks are—from their system of *layers*—known as Lias.[1] From the banks of the Severn they make several westerly extensions, and then stretch away to the southern coast, and reach the English Channel about Lyme Regis. The rocks to the eastward of the Lias belong to the Oolitic series, and to the Cretaceous and Eocene formations; those to the westward being Carboniferous, Devonian, Silurian, and Cambrian rocks. Throughout the whole of the eastern region there is almost an entire absence of those metalliferous minerals, other than iron, which are of commercial value. The iron ores—although abundant in Cleveland, in Northamptonshire, and in Lincolnshire, and occurring in Oxfordshire and the neighbouring counties—have in no case the character of veins or lodes. In distinction we find, to the westward of the Lias, the New Red Sandstone and Magnesian Limestones, with the extensive Coal Measures, Millstone Grit, Carboniferous Limestones, and Shales—presenting evidences of another order: mineral veins of lead and other metals occurring to a greater or less extent in all of them. To the south and south-west of these rocks, we reach the Old Red Sandstone, or Devonian series—and in Leicestershire, Devonshire, and Cornwall, Granitic and Greenstone rocks occur, with Felspathic Traps and Basalt; all these rocks presenting, in the last-named counties, marked systems of lode formations rich in ores of the useful metals.

Thus we learn that to the eastward of the line indicated—that is, from the mouth of the Tees, in the north-east, to the coast of Dorsetshire—there is an absence of the metallic ores of lead, copper, tin, and the like, which occur in a peculiar way to the westward of that series of rocks which belongs to a comparatively recent period, and are distinguished as Secondary or Mesozoic and Tertiary or Cainozoic formations. Iron ores must be excepted—as ferruginous deposits may occur in the most recent as well as in the oldest rocks. We must infer from these facts that there is a definite law—or, probably, a set of laws—with energies, differing in degree, but acting to a common end, which determine the deposition of the metallic ores in the previously-formed fissures of the older rocks, from the Upper Lias to the Lower Silurian or even possibly to the Laurentian Gneiss.

We may state our conviction that metalliferous matter, either in a state of physical purity, or in several peculiar mechanical mixtures, or definite chemical conditions, have been disseminated at all times through a certain class of rocks. These rocks differ greatly in their richness, and also in the variety of these metallic substances. Attention has naturally been directed

to the local characteristics by which any especial region is distinguished. The "nature of the rocks" is constantly appealed to by experienced practical miners, as evidence of their "richness" in metalliferous ores, or of their poverty in such. Although the predictions of the observer—founded on the amount of his lithological knowledge—may be of very different degrees of value, yet, in nearly all cases, it proves that the evidence given by observation is of some real importance, and that it may be, to a certain degree, relied upon as a temporary guide. Admitting this, it is necessary that a short space should be devoted to a consideration of the primary conditions of the metal-bearing rocks, and of the alterations which may have taken place in their mineral characters.

The solid masses which form the superficial strata of the Earth, often called the Earth's *crust* (a term adopted naturally enough from the hypothesis that this globe was at one time a fluid, possessing a certain amount of homogeneity, the result of igneous action, which slowly cooled from the surface). It is useless—especially in a work of this kind—to wander into speculations respecting the beginning. Vast mutations, continued through countless ages, have constantly been in progress, and the earliest forms of matter have undergone mechanical or chemical changes, by which all the known conditions of rock formation have been produced. In addition to the purely physical phenomena, there must have been through all time, as the result of the action, either of heat, of electricity, or of chemical influences, vast changes—often called *metamorphoses*—which eventually produced those lithological varieties with which we are acquainted. It should, however, be remembered that our knowledge is limited to about 4,000 feet beneath the very surface upon which we exist, and that we know nothing of the enormous mass extending to the centre of the globe.

The changes which have taken place are very varied in their character. Some rocks are simply formed by the abrasion, or disintegration, of previously existing masses, the fine matter worn off being held in cohesion by the molecules having been subjected to considerable mechanical force. The detrital matter in other cases has been consolidated by some cementing substance, such as silica or lime. Many of these have again been disintegrated by the influences of chemical action. Evidences of convulsive force are seen in some. Fragments have been broken off, and these,—sometimes water-worn pebbles,—have been agglutinised into conglomerates, or angular fragments have been cemented together, forming breciated masses. Other, and not unfrequently vast, strata have been exposed to the influences of heated masses of igneous rocks which have been protruded through them.

GRANITE or MOORSTONE.—The first is a modern name given to this rock by Italian writers—*Granita*, i.e. *è granis composita.* The parts of Granite are not homogeneous, but are different concretions of quartz and mica. Such is the definition of Granite given by Pryce in his "Mineralogia." The same author continues as follows: "The varieties in the west of England are of five sorts—the white, the dove-coloured, the yellow, the red or Oriental granite, and the black or true Cornish. Either of these as a stratum is called a *Hard grouan country* (in the Swedish tongue, *Graberg* and *Grasten*). *Grouan strata* are disposed for tin, which in such situations

is generally of a rich quality, or cannot long be sought after or wrought in its almost impregnable walls. They are seldom likely for copper ore, and were long thought to be wholly adverse to that mineral, till the great mine of Tresavean proved that rule exceptionable." *

Of the varieties of ordinary Granite Mr. Joseph Carne remarks †: "With respect to the more particular and local varieties of Granite, to describe them would be an endless task. They are almost as many as all the possible combinations of its three (or, including shorl, we may say its four) constituent substances can give rise to."

There are, however, four varieties of Granite which have more especially some relation to mineral productions. 1. A variety, which may be called porphyritic Granite, is studded throughout with large crystals of felspar. 2. A variety which deserves notice from the almost uniform minuteness of the grains of which it is composed. This Granite prevails on the sides of Pertinney Hill in St. Just, and on the northern edge of Dartmoor, not far from Oakhampton. A third variety is formed of a conglomerate of large crystals, and frequently in a state approaching disintegration. Much of this is seen in St. Just, and at Stenna-Gwyn in St. Stephens, St. Austell. A schorlaceous variety constitutes the fourth. It is abundant in St. Just and Sennen, and is extensively scattered over various parts of Cornwall and Devon.

The following remarks, derived from Mr. J. Carne, place the rocks of St. Just and their relation to the mineral veins in a very satisfactory view: "The Granite ridge or junction takes place at Cape Cornwall, and continues through St. Just district, where it is plainly to be seen again at Pendeen fishing cove, the distance of two miles, and at the Gurnard's Head and at Wicca Pool in Zennor. The junction is nowhere more than half a mile inland throughout the whole district. The mineral lode, in passing through the junction, generally improves in value, and frequently very rich deposits of tin and copper are found following the dip of the Granite, or, as it is termed, riding the junction. Generally speaking, the Killas in the cliff is a mixture of Clay-Slate, extremely hard, with patches of Greenstone and Hornblende Slate, denser and of finer grain where it joins the Granite. Whenever the lodes come in contact with any of these patches, or cross a course of Greenstone, they invariably become small and poor, frequently being nothing more than a small leader, just sufficient to guide the miner, on the course of the lode. When the Killas of St. Just contains a mixture of quartz and mica it is considered very favourable for mineral. The brown Killas is hard, and contains more tin than copper. The pale blue variety generally accompanies the rich lodes of copper. The miners apply the word *Killas* to Clay-Slate, micaceous Slate, and hornblende Slate if it is soft. Clay-Slate of the hardest degree is, strictly speaking, true Killas."

"The china stone of St. Stephens," says Mr. Carne, "and other parts might perhaps be mentioned as another variety of Granite, but scarcely

* Pryce's "Mineralogia Cornubiensis," p. 75. 1778.
† "On the Granite of the Western Part of Cornwall." By Joseph Carne, Esq., F.R.S., &c. ("Transactions of the Royal Geological Society of Cornwall," vol. iii. 1828.)

any of it occurs in the western part of Cornwall, and, besides, it owes its *difference from ordinary Granite to decomposition.*" The latter portion of this quotation has been printed in italics for the purpose of drawing attention to what appears to be a questionable hypothesis.

That china clay and china stone have usually been referred to decomposition—produced by some local cause—must be admitted, and there is a large amount of evidence which goes to support that view. The felspar of the Granite is regarded as the constituent most liable to decomposition. In the neighbourhood of Wheal Coates, St. Agnes, it is not unusual to find the crystals of felspar converted into china clay, or *kaolin*, and sometimes the clay itself is removed and the cavity left is filled in with the black oxide

Fig. 14.—Granite Tor on Rosewall Hill.

of tin. These pseudomorphs are of great interest. They have been occasionally found in other localities, but they are by no means common. A careful examination of the china clay quarries around St. Austell, and at Lee Moor on Dartmoor, lead to the supposition that these deposits appear rather to resemble Granite which has never been properly formed, than Granite which has undergone decomposition.

The only conclusion to which we can legitimately come with respect to Granite, is to admit that all known evidence is in favour of our regarding it as a rock of igneous origin, to a certain extent. The quartz, mica, and felspar, which may be regarded as the more important constituents of this rock, were probably at one time subject to a temperature sufficient to keep the silica and alumina and the alkaline constituents in a condition of plastic fusion. The Granitic mass was then under enormous (probably subaqueous) pressure, which was maintained for a prolonged period, during which crystallization was going on, and in this condition it was forced through the surface rocks of that epoch. The detection by Sorby of molecules of water in the quartz crystals of the Granite, sufficiently proves the presence of water during the period of formation.

If we examine a section of a Granite quarry, we shall find a structure which can only be explained by supposing that vast pasty bubbles were forced through the superincumbent strata. These may be represented by

the sketch of actual Granite tors on Rosewall Hill, near St. Ives, and the accompanying theoretical diagram.

Although this diagram, Fig. 15, must be regarded as being, in the main, hypothetical, yet it represents the general conditions, which the author has studied in the Penryn Granite quarries, and in those of the Cheesewring, near Liskeard. Such masses as B, C, D, D, were sufficiently obvious. The jointed structure is only such as would be produced in the process of cooling or hardening a plastic mass. The lines *a, a, a, a,* are lines of fracture dependent upon some greater cause, corresponding with the fissures, which eventually, by becoming filled in with metalliferous or earthy minerals, form mineral veins. The shaded portion marked A has been observed in several instances, and the conditions are those which would be produced by the interference of these Granitic bubbles with each other. The Granite at A is always more or less disintegrated, and very frequently the space indicated forms the channel through which the surface waters are drained away.

The quarrymen are quite familiar with this condition of Granite, and supposing they were working from the point A to the point B, they would

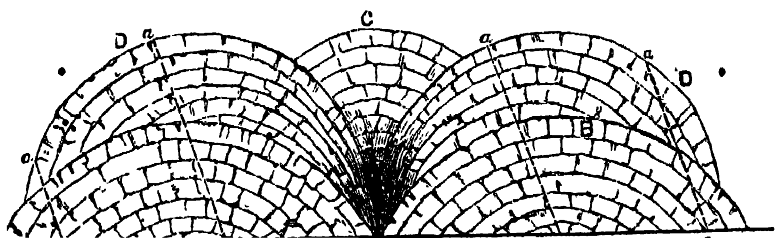


Fig. 15.—Hypothetical Granite.

say they were "*gaining the quarry,*" that is, they found the beds rising in front of them. After having reached B the curve of the beds was a decline from them, and this they express by saying they are "*losing the quarry.*" It will be obvious, we think, to all who have their attention directed to the Granite tors of the Cornish hills or of Dartmoor, that they all indicate this curvilinear system of the beds, allowing only for the disintegration due to atmospheric causes. Dr. Boase noticed this peculiarity in the Cornish Granites. He says: "Whenever the Granite is exposed by quarries on the sides of hills, near the junction with the Slate (as at Kit Hill and in the parishes of Mabe and Constantine), the surface *has not only a rounded form,* but is also traversed by curved fissures and joints." *

Some years since it was suggested that the Great Exhibition of 1851 should be commemorated by the erection of a monolith of Granite of not less than seventy feet in length. It was thought that this, mounted upon a cubical mass of about thirty feet, giving together a height of a hundred feet, would be an imposing object, and secure permanence to the spot on which this remarkable gathering took

* A C in Fig. 15, which is copied from one of the Granite quarries in Mabe, is an imperfect portion of the mass formed at the junction of some of the rounded masses, and which will represent that condition of Granite which is found to be most metalliferous. Captain C. Thomas and Mr. W. J. Henwood have both drawn attention to the difference between what they call "mine granite" and "building granite." D, D. This will be referred to in a future page.

place. The author of this volume was requested to ascertain if a block of Granite of the required length could be obtained. The greatest length which could be obtained was about fifty feet. It was from two quarries only (the Cheesewring, near Liskeard, and the Lemorna quarries, a few miles west of Penzance) in Cornwall that such lengths could be got out. All the beds presented a more or less curved surface.

This condition is very satisfactorily described by the Rev. J. G. Cumming, of the Isle of Man, from whose book the following extract is made :—

"Now let us examine this great ellipsoidal Granitic bubble. It rises up in a fine dome, around which mantle a series of metamorphosed rocks," &c. Baron von Buch, in his description of the Brocken in a paper read before the Berlin Academy of Science (December 15th, 1842), has given us a good insight into the structure of these Granitic bubbles . . . The regularly circular form of Granitic mountains, and the breaking up of the surface into millions of blocks, seem to depend on one another in some relation. He suggests that Granitic mountains are lifted up in a certain *plastic condition*, not as lava, in a perfectly fluid state, filling up fissures, but in thick ellipsoidal bubbles, by forces acting from beneath. In the ultimate cooling and contraction of the upper dome-shaped surface it will necessarily break up into a vast number of blocks, forming what have not been inaptly termed 'seas of rocks.' At the same time the Granite arranges itself in cooling into large concentric layers, gradually diminishing in size until at last the innermost nucleus appears cylindrical, as may be seen in bosses of small extent, and this remarkable concentric arrangement may very readily be mistaken for stratification." *

All Granite rocks are, as far as our observation has gone, intersected by larger or smaller veins. These frequently put on the appearance of being Granitic veins, which have been sometimes called contemporaneous. Contemporaneous such veins could not really have been. It is quite possible that while the larger mass was in the process of cooling, there might have been an injection of matter of a higher temperature, and consequently in a more fluid condition. Granite veins proceeding from the great central masses, penetrating the Granite itself and piercing the neighbouring Slate rocks, are strong evidence that a considerable degree of fluidity must have prevailed at one time in the erupted mass. It is highly probable that fissures previously formed may have been filled with the erupted matter, and that these fissures have been enlarged by the process of crystallization. Although Mr. Carne himself uses the term, yet his own description—which is very correct—is directly opposed to contemporiety.

"The observer," he says, "is struck with the frequent occurrence of what appears to him to be *contemporaneous* Granite veins, but on a minute inspection these will generally be found to be veins of quartz, but their influence appears to have extended to the Granite which immediately adjoins them; at least, the adjoining Granite is usually of a different kind from that of the neighbouring mass, although forming one body with it. This difference in some places extends several inches on each side of the vein, which itself is not more than an inch or even half an inch in width. If the

* "The Isle of Man." By the Rev. Joseph George Cumming, M.A., F.G.S. 1848.

quartz of the vein is at all disintegrated, the Granite which adjoins it on each side is decomposed, and this is frequently the case even where there is no disintegration in the quartz. But decomposition, although doubtless the frequent cause of the dissimilarity of the Granite, is not the sole cause, for there are numerous instances in which neither the quartz nor the adjoining granite has undergone any change, and where this is the case the latter is much harder than that of the mass which is farther distant from the quartz vein. The Granite close to the vein is frequently of a red colour, and it generally contains more felspar and less quartz than the Granite mass near it. It is possible, therefore, that at the period of the formation of the Granite the matter of the quartz, instead of combining generally with the other substances, arranged itself, perhaps by *elective affinity* (?), in separate although contemporaneous veins, and in consequence the Granite close to it contains a smaller quantity." *

Mr. Carne, in the paper already referred to, directs attention to some curious conditions which are connected with the existence of Granite boulders that are found on the western coast of Cornwall. "The occurrence of rounded and water-worn masses of stone, of all sizes, in situations where they could not have been originally placed, is not uncommon. . . . . The most remarkable circumstance of this kind which is to be found in Cornwall occurs at St. Agnes Beacon, where, nearly 500 feet above the sea-level, a layer of sand occurs of the depth of 6 feet, and immediately under it a layer of rounded stones. . . . . There are, on the western coast of Cornwall, numerous instances of a similar kind, although none so much above the level of the sea."

Before quitting this division of the subject, it cannot fail to be instructive to give the expression of opinion of one of the most experienced of Cornish miners, Captain Charles Thomas, who was at the same time a man of original views. He says :—

"If a central line, due magnetic east, be drawn from St. Just on to Tavistock and Exeter, and two other parallel lines be drawn, one north and the other south of this central line, and six miles distant from it, forming a zone of twelve miles in breadth, this zone will be found to enclose nearly all the productive mines of tin, lead, or copper in the two counties. On Dartmoor, perhaps, this zone may be flattened out a little, but the metallic deposits there are proportionably diffused, no considerable quantity being found in any one locality. An opinion has been very prevalent, especially in the western part of the county, that a lode to be productive should be situated to the north of Granite. This holds good only to the west of Truro. The great tin and copper district east of Truro, especially about St. Blazey, lies to the south of Granite. The great mining zone does not follow the Granite, but continues in the direction of a right angle to the present magnetic current. And whenever, in that direction, the great beds of secondary Granite, compact Clay-Slate, Greenstone, with granular Killas and Elvan courses are found, there the greatest deposits of copper have been found. These beds do not everywhere extend to the whole width of the

* "On the Granite of the Western Part of Cornwall." By Joseph Carne, Esq., F.R.S. ("Transactions of the Royal Geological Society of Cornwall," vol. iii. 1828.)

twelve miles, but large tracts sometimes occur, of several miles in length, where the strata are utterly unfavourable for mining operations. The tract extending from Chacewater to several miles east of Truro may be adduced as an example. In strata of this character, lead, silver, zinc, and sulphur are the only ores likely to be found there. The strata north and south of this twelve-mile zone seem unfavourable for mining operations. Hitherto, at least, profitable mining has been almost entirely included within that width."

"For the clearer understanding of the geology of this district," Charles Thomas compares the "counties of Cornwall and Devon, as far east as Exeter, to a large flatfish spread out into the sea. Let the west of Cornwall, from Hayle and Marazion to the Land's End, represent the head, the rest of Cornwall the body, and Dartmoor and vicinity the chine and tail. Primitive Granite will represent the backbone; secondary Granite and compact Clay-Slate the muscular fleshy fibres from the back to the sides; Greenstone and granular Killas, intersected by Elvan courses, the ribs and softer parts of the fleshy sides; and the muddy Killas, shelfy Slate, and secondary Limestone, the fins and belly fat. In the secondary Granite and quartzose micaceous Clay-Slate, nearest the backbone, are the great deposits of tin; in Granite a little further removed from the backbone, as well as down the sides in Greenstone, compact and dark-coloured Killas near Elvan courses, and in light-coloured and white Killas when granular, will be found copper. Branching off at right angles from the copper and tin deposits, in the soft flesh of the ribs, lead will be found. In the backbone itself and the extremities, the primitive Granite and the shelving Slate, exist excellent materials for walling and roofing, but no metallic ores to remunerate the adventurer for the toil of working. One must not conclude from this that no mining strata exist in Cornwall or Devon beyond the twelve-mile zone, to which the mining operations have for the most part been hitherto confined. Primitive Granite in abundance is found about Camelford and stretching eastward towards Launceston. I am not aware that the ground in that neighbourhood has been sufficiently examined to ascertain whether secondary Granite, granular Killas, Greenstone and Elvan courses form its outskirts and fill up its hollows, as in the existing mining zone. Should it prove to be the case, another mining district may hereafter be explored by another generation."

In another lecture the same authority,—speaking with all the decision which has been derived from long experience and always careful observations,—writes as follows. (It is preferred that those extracts should be given in the observer's own words. They are the words of an aged practical miner, speaking to practical miners, and they therefore carry much weight with them. Captain Charles Thomas was a man of the utmost honesty, but with strong prejudices; therefore his hypotheses should be carefully weighed before they are adopted as being strictly reliable.)

"As a considerable portion of our profitable mining operations is carried on either in or contiguous to secondary Granite, never extending into what is denominated primitive, although varied in its structure and composition in different localities, the following are some of the characteristic features of the productive Granite: fracture rough and irregular, very jointy, frequently

containing hornblende and chlorite, is traversed by irregularly-formed Elvan courses, whilst portions of it, like ribs, project from the main body into the surrounding Slate. Its localities are some of the outskirts of primitive Granite districts, the hollows between high hills, the *base* of lofty peaks rising from the interior of such districts, and sometimes rising in such situations into small hills itself. The configuration of the landscape alone to an experienced eye would for the most part indicate the position of this kind of Granite. A narrow margin only of some Granite districts is of this kind, although a thin layer of it sometimes overspreads pretty large portions of primitive Granite. The largest extent in this neighbourhood (Camborne) is found extending eastward from Troon, through South Francis, South Basset, and Wheal Buller, thence south-east to Tresavean. This Granite at Tresavean mine, where it forms a junction with the Clay-Slate, is of a great depth. In tracing it westward it is found to get gradually thinner. At East Francis, a mile and a half into the Granite district, it ceases to yield copper. Nine-maiden Downs is on the primitive Granite rock, with only a very thin covering of the tin-producing Granite. The primitive rock extends over a large part of Stithians, Wendron, and the south of Camborne, and in those places no mine of value has been discovered. Passing on to the south-west of this district of primitive Granite, we again meet with a margin of the secondary kind, and then we find Wheal Trannack, Wheal Trumpet, and Trevennen mines. Trumpet Consols and Wheal Lovel are found on the flats of the same neighbourhood, and Porkellis United, three miles from Killas, in a hollow between bold hard hills. In this district, as well as in other tin-producing localities in the interior of Granite ranges, shoots or ribs from the prominent hills intersect the adjacent country, and coming in contact with the lodes, render them unproductive. Mr. W. J. Henwood, in his remarks on the Granite in which Wheal Trannack and Wheal Trumpet are situated, says truly that where these mines were rich the Granite was *coarse-grained*, but becoming at deeper levels close-grained, the lodes failed to poverty. Between the primitive Granite hills of Godolphin and Tregoning a portion of secondary Granite occurs, the site of the Great Work mine. Thin at the top, it deepens eastward to the base, and while it lasts the mine has been found productive, but on reaching the primitive bed—the continuation of the adjacent hills—the lodes immediately become poor.

"Among other localities of secondary Granite may be enumerated the whole of Carn Camborne, the west, north, and south parts of Carn Entral, and the northern part of Carn Brea. This distinction between the two kinds of Granite as found on the eastern part of Carn Entral, and their limits, by the form of the surface, can be clearly seen from Dolcoath. From Carnanton is perceived, with equal clearness, the difference between the body of primitive Granite of the Entral Hill and the secondary sort sloping down towards the south, in which Condurrow mine is situated. From near Carn Brea Castle also can be seen the tops of the secondary Granite, thin at first, and gradually thickening till it forms a tolerably deep bed at the Carn Brea mines.

"The Carradon Hill, at its south base as well as the west, stretching away some distance into the Craddock Moor, and filling the intervening hollows, has also a border of secondary Granite, but getting thinner and thinner as it

recedes from the primitive hill, until the rock, without any sign of metallic life of value, fills up the rest of the district. This diminishing thickness of secondary Granite was clearly shown in the St. Clear mine, situated on the low ground west of Craddock Moor. At the surface, consisting of secondary Granite, the lode was very large, containing a large quantity of gossany matter. The primitive rock, however, was soon reached, and the lode found split into innumerable strings, leading to the abandonment of the mine. Phœnix mine, situate at the foot of the Cheesewring, but not productive westward in the primitive rock of Granite, is another case in point.

"Another example of secondary Granite, under similar circumstances, occurs on the east side of Rosewall Hill, sloping down towards St. Ives. Rosewall mine, situated half way up the hill, was rich in tin while the lode continued in the upper covering, but on reaching the primitive rock it failed, and became worthless. St. Ives Consols is in a deep bed at the base of the hill.

"As productive Granite commonly occupies the *base* of lofty hills and the margin of some extensive Granite districts, so the bold prominences and unbroken central portions may be safely assumed to be essentially of a primitive character. The principal hills and districts of this kind have been already named in pointing out the localities of productive Granite. Among other hills of the same kind, in the west of Cornwall, may be named Castle-an-Dinas (north of Penzance), Carn Menellis, and Carn Marth (at Gwennap and Wendron); in the eastern part, Brown-Willey, Rough-tor, and Kit Hill. Primitive Granite, when not bordered by secondary, usually passes gradually into other substances. Sometimes crystalline quartzose rock intervenes between it and the Clay-Slate. Such is the case between Tregoning Hill and the Clay-Slate at Wheal Vor. At other times schorlaceous rock (schorl and quartz) occupies that position. Instances of this kind occur on the outskirts of Dartmoor, Brown Willey, Carn Menellis, east part of Carn Brea, and Land's End. Roche Rock is composed of this substance.

"Primitive Granite may be further distinguished by the perfection of its character, if I may be allowed so to express myself, composed chiefly of quartz, felspar, and mica, or talc. It contains no heterogeneous matter like the secondary kind, having no hornblende or other ingredients intermixed. The crystals of felspar are also more perfect than in the secondary kind, and being less jointy it may generally be split with smoother surfaces. The ideas suggested by its structure, as well as by the lofty hills and unbroken plains formed out of it, are those of substantiality, firmness, immovability, just such as we might expect it to be coming fresh from the hands of the Creator; exhibiting in the mass no signs of disturbance by the elements, no rendings nor upheavals by earthquakes, &c.

"After many years' experience and careful observation, made in all the mining districts of Cornwall and Devon, I have come to the conclusion that the two kinds of Granite which I have distinguished as primitive and secondary differ as much in many respects as Granite and Elvan; *that primitive Granite contains no metallic ores of value; that tin ores are found nearest to it, and copper ores of value never in it, nor very near to it.* In secondary Granite, where lodes of suitable size, character, and direction

occur, some of our most valuable mines have been found, and others may be looked for."

This quotation, from a lecture by so very experienced a miner as Charles Thomas, will convey a correct idea of the generally received hypothesis of mineral lodes.

The metalliferous character of the mineral *lodes* are, it is supposed by many observers, to be determined by the *mechanical structure* of the neighbouring rocks,—by *the position of* these rocks,—and by their chemical composition. *Granite*, *Slate*, and *Elvan* are the metal-inducing strata of Cornwall. Their hardest portions are always quartzose, and these indurated portions are rarely of any value for mineral deposits. A fine-grained Granite rock, such as is called *Whet-stone*,—is an unfavourable indication for metallic deposits. That of a coarser texture, containing large, well-developed crystals of felspar, is equally of an uncongenial nature. If the Granite rock be of a medium character, being neither very fine nor particularly coarse-grained, and the imbedded felspar be of a greenish or brownish hue, and the planes of the crystals rather indeterminate, the character of the rock is considered to be a favourable one. If the basis of the rock consists of a pale, greenish felspar, with quartz and mica, and occasionally schorl, the lodes passing through it may be regarded as giving fair expectations for being productive of tin.

A thickly lamellar brownish-purple Slate rock, which exists around Carn Marth, is traversed by the lodes, which always contain copper, and frequently tin also. A Clay-Slate (*killas*) of a pale greyish-yellow hue, passing into a dull white, and here and there marked between the laminæ with a few bluish spots, with internal lamellar structure, but in a state of decomposition, accompanies the richer portions of the copper lodes of Cornwall. Although copper *lodes* have been productive in this pale-coloured slate, when they pass through it into a deep blue quartzose Killas, the mineral deposits either dwindle gradually away or suddenly disappear.

Mr. Henwood is impressed with the idea that the colour and character of the rocks materially influence the mineral nature of the *lodes*. He says: "Pyrites are found in a dark blue Clay-Slate, homogeneous in texture, of a glossy and silky lustre, having a very even lamination, and opening in thick horizontal joints, which coincide with the cleavage planes. In this rock the lodes seldom contain tin ore. If the Slate assume a deeper hue, the copper ore which the lodes may have previously yielded are replaced by iron pyrites, and if the rock becomes quartzose, even the iron pyrites disappear." This agrees entirely with my own observations, but it is exceedingly difficult to offer an explanation of the causes which lead to these remarkable changes. The Slate, wherever tin ore abounds, is of a tolerably uniform character, thick bedded, and blue, with an occasional greenish tinge (this is almost always produced by the percolation of water charged with decomposing vegetable matter, or impregnated with carbonic acid). Its diminution in the depth of colouring, and a softening in the texture of the rock, are usually unfavourable signs.

In the greenish and blue varieties of Slate but few lead lodes occur, and these are generally at no considerable distance from the Granite.

"Whether the rocks are Granite, Elvan, or Slate, when the joints which are parallel to the lodes in their directions fall towards the *lodes* in descending, it is considered a favourable indication; whilst, if similar joints separate from them as they go downwards, it is considered an index of poverty. In all these cases many transverse joints seem to exercise an unfavourable influence on the produce of the *lodes*, and often a *course* of ore is directly cut off by a joint running across the *lode*. In all cases I believe this can be shown to be the result of mechanical disturbance" (*Henwood*).

Mr. Henwood truly remarks that the cleavage planes of the schistose Slates are almost invariably *curved* and *contorted* whenever the rock is quartzose, and in such cases it is usually very fissile, and the laminæ are highly inclined. Either of those conditions is accounted inauspicious. When the cleavage planes are regular and moderately inclined, and when the rock exhibits a thickly lamellar structure, the lodes which traverse it may be expected to be productive.

Professor W. W. Smyth's address, delivered before the British Association at Plymouth, in 1877, on "Physical Phenomena connected with the Mines of Cornwall and Devon," should be consulted as one of the most compendious statements published on this interesting subject.

When the consideration of the mineral veins of this district is reached, it will be shown that there is evidence that several hundred feet of the surface have been removed, and from this, in all probability, the detrital of tin of Trevaunance, of Perranzabula, and other districts have been derived. It therefore becomes important to indicate the evidences of these great disturbances. The clay-pits and the beds of sand worked around St. Agnes Beacon furnish that evidence in a very convincing form. Two examples are therefore given. The first figure is a correct section of one of those clay-pits. Above the line where the woodcut commences there exist twelve feet of fire-clay, and ten feet of overburthen, consisting of earthy and decomposed peaty matter.

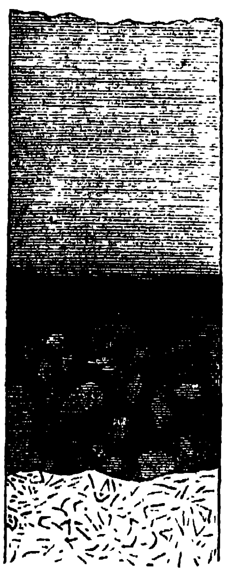


Fig. 16.—Clay-pit at St. Agnes.

In this clay (Fig. 16) large masses of the neighbouring rocks are found imbedded. In Fig. 17 we have exposed a fine section of the rocks of an old sea-coast. This was brought to light by extensive workings for tin, which were carried on for some years. Resting upon the rock (4), and dispersed through the clay resting upon it (3), were numerous blocks of slate and granite, some of them water-worn, but some still preserving their angular edges. Above this there was a considerable accumulation of sands (2), of varying degrees of fineness, and earthy deposits (1), with various kinds of decayed vegetable matter, up to the surface soil (5).

From Cape Cornwall southwards, near the commencement of the Granite coast, the boulders begin, and extend, varying much in their thickness, around Land's End. At Portnanven Cove, in St. Just, are two beds separated from each other by a mass of solid Granite. The western bed is 10 feet

in thickness and about 80 feet long. The eastern bed is at least 200 feet long and 20 feet thick. At Wheal Oak point a *Guide*—a name given in the St. Just district to an iron lode—occurs. It is about 6 feet wide, and in it many boulders are found. Several other examples might be referred to, but these appear sufficient for our purpose. At Wheal Carn mine, at the height above the level of the sea of at least 500 feet, the miners in clearing out an old shaft passed through a bed of boulders of a thickness of about 15 feet. In the tin lode of Ding Dong mine, in Gulval, near Penzance, numerous rounded pebbles were found in the lode. And at Relistian mine a mass of pebbles was discovered in the tin vein about 12 feet square. These facts, and many similar which might have been quoted, serve to show that the filling of the fissures was more recent than the disintegration of the Granite.

At *Tol-Peden-Penwith*,—or, as it is sometimes called, the St. Leven Land's

Fig. 17.—Old Coast at St. Agnes.

End,—are some fine examples of Granite lodes piercing the Granite mass. These are usually of a finer grain than the mass itself They generally vary in colour, and appear to affect the Granite through which the vein has penetrated. Sir Henry de la Beche, who gave much attention to the phenomena, says: "The veins are merely joint or divisional plane fissures, filled by quartz or other mineral substances, which are seen in the continuation of the same or similar fissures in the mass of the adjoining Granite." The penetration of those Granite veins through the Slate (*killas*) show very clearly the conditions under which they were formed. The following plan of a set of Granite veins on St. Michael's Mount, Fig. 18, is by De la Beche.

The shaded portion is Slate; the Granite veins are marked *a a a*, and *b b* is a joint fissure with a general direction about east twelve degrees north, west twelve degrees south, traversing both Granite and Slate, the amount of of the joint, combined with the course of the veins, having

produced the appearance of a slight heave of the rock through which it passes; *d d* is a smaller joint fissure parallel, or nearly so, to the larger *b b* filled with mica where it traverses the slate, but containing more quartz, and being altogether filled with that mineral, where the joint fissure traverses the Granite veins.

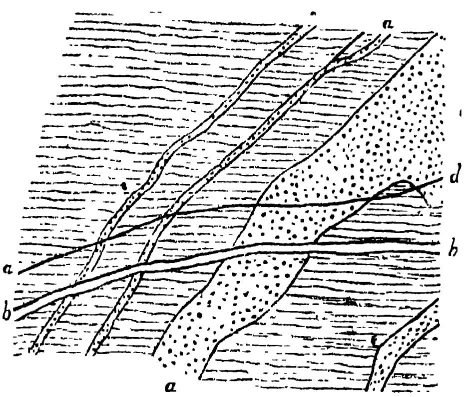


Fig. 18.—Granite Veins, St. Michael's Mount.

The following example of a Granite vein traversing a Slate rock is drawn from an original survey by the late Mr. Thomas, whose name is associated with some of the best Mining maps of Cornwall (Fig. 19).

It may appear that more attention than was necessary has been given to the Granite veins and the evidence of disturbance shown by the boulders collected in beds and caverns, but it will be seen that these phenomena have a peculiar relation to the "Elvan courses," as they are called, which have *certain special* bearings on the question of mineral lodes.

SCALE ABOUT 20 FMS TO 1 INCH

Fig. 19.—Granite Veins at Trewavas Cliff.

ELVANS.—The relation—or the supposed influence of this rock on the mineral veins—is so marked that it demands especial notice. The following notice from Pryce shows how the old miners regarded this rock: "*Elvan* at a shallow level is a gritty stone, most like a coarse freestone, but in depth is exceeding hard. The two most common colours of this stone are a bluish grey and a yellow freestone. It commonly yields great quantities of water, and we take it to be of the same kind with that stone which lies on the culm veins in Wales. It sometimes runs in a direction north and south, contrary to the metallic veins, which generally keep their course through it, but the lodes are frequently squeezed up by its accompanying them some length in their course, or are split into many small branches. Sometimes the fissures or lodes are thrown short on one side, out of their direct course as it were, by the extreme hardness of this stratum, and afterwards they recover their course again. At other times the metallic veins are elevated or depressed by it, though they always recover their former direction, and unite again, for this stratum wears out at a great depth and is succeeded by Killas." (This is illustrated in Fig. 20.)

Our future remarks will show how much at fault this author was in his hypotheses. We find in addition to the true Granite veins long lines of *Granitic* and *felspar porphyry*, to which the term of *Elvans* has been given.

They are found traversing both the Granite and Slate in a continuous body, and in their mode of occurrence remind the observer of *Trap-dykes*, and they differ from them only in mineral composition. "Those *Elvans*," says Sir Henry de la Beche, "which traverse the Granite and Slate are of an age posterior to the consolidation of at least that portion of the Granite which they cut through. With respect, however, to those which only traverse the Slate, the time of their formation, or *rather the formation of the fissures into which the igneous matter of which they are composed was injected*, is not so clear; some may have been formed at the epoch of the intrusion of the great masses, while others may even have been produced after the *Elvans* which traverse the Slate and Granite."

There is a want of the usual clearness which always marked the deductions of De la Beche in these remarks. This arises from his holding the view that fissures were pre-existing, into which the pasty mass of the Elvan was projected. All the conditions of the Elvan courses rather point to the forcible injection, under very great pressure, into the already solid rock, producing thus, as shown in our section of Granite veins, a peculiar tendency to an arborescent form.

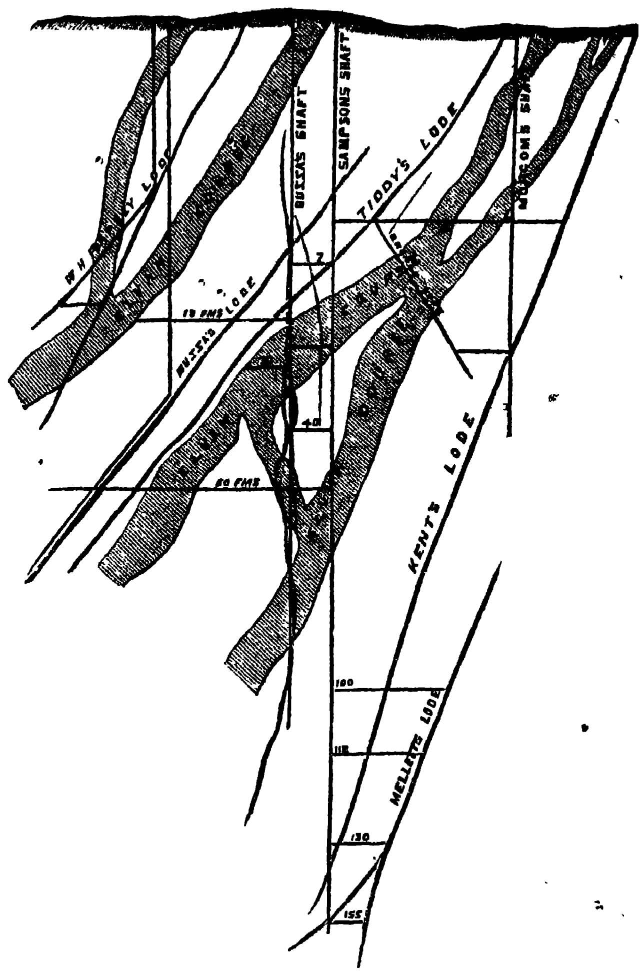


Fig. 20.—Elvan Courses and Copper Lodes.

Be this as it may, we gladly quote his description of the more important Elvan courses of the West of England.

"These Elvan dykes vary from a few to 300 or 400 feet in breadth, and though comparatively narrow, may even be traced satisfactorily for several miles. One of the longest hitherto discovered is that which runs from Darlington, near Marazion, for twelve miles by Wheal Fortune, Corbus, Treganhorn, Cayle, Herland mine (near Gwinnear), Roseworthy, and Camborne to Pool, sending off a branch near Cayle about five miles long, which passes by Carnhell Green, Cassawson and Tregear into the Carn Brea Granite. How far this Elvan may extend to the south-westward it would be

difficult to say. That which runs along with Penzance pier and is continued by the Wherry mine is not far out of the line." *

For an exact description of all the more important elvans, the reader is referred to De la Beche's Report on Cornwall and Devon, which, studied with the assistance of the maps of the Geological Survey, will give all the information which can be required. A remarkable group of Elvans is represented in the accompanying woodcut, Fig. 21, extending from Redruth over the well-known mining parish of Chacewater.

These Elvans have a common mineral character, being generally composed of a felspathic or a quartzo-felspathic base, containing crystals of felspar and quartz, and sometimes schorl. Many of these Elvans are used

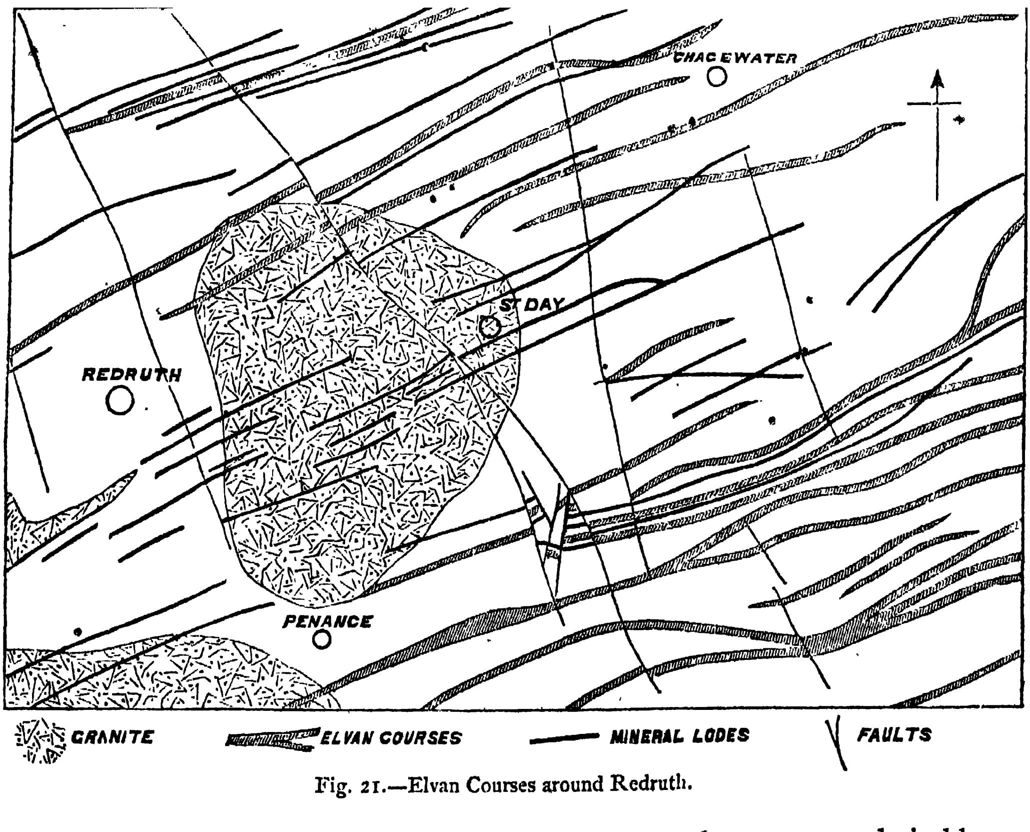


Fig. 21.—Elvan Courses around Redruth.

extensively as building stones, for which purpose they answer admirably, as they are found to resist atmospheric influences, and to endure for long without change.

"By *Elvan*," says Mr. Henwood,† "I intend a rock possessing the same constituents as Granite, which, as in that rock, vary in their numbers and proportions, of which the structure is always porphyritic. It is always a subordinate rock, passing indifferently through all others in the metalliferous districts, and may be denominated a vein or dyke according to its size, which is extremely variable."

* "Report of the Geology of Cornwall, Devon, and West Somerset." By Henry de la Beche, F.R.S., &c.

† "The Metalliferous Deposits of Cornwall and Devon." By William Jory Henwood. 1843.

Elvan courses are in general east and west, and north-east and south-west, the average being about twenty degrees south of west. Some few run several degrees northward of west. Elvans dip generally from forty to sixty degrees, and they incline more frequently to the north than to the south.

The Elvans traverse Granite and Slate alike without interruption, and their character varies with the rocks through which they pass. In Slate they generally consist of a compact base of felspar and quartz. In Granite, Elvans are usually of the same materials as that rock, but in different proportions, and varied in aggregation.

Innumerable joints traverse the *Elvans* in all directions, dividing them into small, irregular-shaped blocks.

Plumbago has been found in isolated masses in the Elvans, and rarely, copper pyrites. Many of the Elvan courses have been worked for the tin ore they contain.

Werner characterises the *Elvan* as an intimate mixture of dense or compact felspar, in which a little quartz may be occasionally seen. Some specimens, he says, have a close affinity to the *thon-schiefer* of the Swedes. Mr. Hawkins submitted various specimens to Werner. He describes them in the following order.* The globules on the Chyanoweth Elvan consist of quartz and mica intimately mixed. This together with the Elvan from Peden-avonder in Sithney are a fine veined variety of Granite. The Elvan from Porkellis, Bal, and Breage is the same, but the felspar is decomposed. The Elvan from Polgooth is an argillaceous porphyry. The Pentuan stone is common porphyry.

The Elvan dykes extend through Cornwall into Devonshire, and may be traced in Lundy Island. De la Beche thinks the Granitic rocks of North Devon are "patches or parts of dykes, analogous to the Elvans of Cornwall and South Devon, and may have been ejected, like them, after the sedimentary rocks they traverse have suffered great contortions and displacements."

It will be seen that the Elvans of the Gwennap district (consult the Map) all run in a similar main direction, from the north of east to the south of west, and that all the mineral lodes of that neighbourhood have a near approach to the same. In some cases strings of black tin and pyrites are found within the fissure of the Elvan dyke, and occasionally small patches of mineral matter have been found in the Elvan itself. De la Beche informs us that an Elvan which cuts through the Old Mulvra mine in its course from Trelyon Mill, near St. Stephens, to Flat-point Rock, in St. Austell Bay, holds nests of yellow *bisulphuret* of copper, apparently isolated, and varying from several tons to a few ounces in weight. Plumbago was found in small nuggets by Mr. Robert Were Fox in one of the Elvans near Devoran, in Falmouth Harbour; and Mr. J. S. Enys gave the author of this volume a small piece of plumbago, one of several, found in an Elvan running through his property at Enys, near Penryn. When we arrive at the consideration of the phenomena of mineral veins, the conditions under which they are relatively found will be the subject of attention.

* "On the Cornish Rocks." By John Hawkins, Esq. ("Transactions of the Royal Geological Society of Cornwall," 1822.)

A large bed of Elvan interspersed with *killas* traverses Coisgarne Downs, extending from the north part of United mines, to the south part of Wheal Virgin, and eastward through the downs, being probably connected with veins from the east and west. In many of the mines are found *irregular* masses of Elvan of different degrees of hardness, scattered at various depths, no indications whatever of those Elvans appearing on the surface (Figs. 20, 21).

Elvan courses are often of considerable width, and they have been termed by the miners *courses* or *channels*, to distinguish them from veins. They are usually composed of hornblende, quartz, and felspar, and may be regarded as an hornblendic porphyry; but the term *Elvan* has been applied by the miners to rocks which differ materially from each other. *Elvan* in many cases becomes a *vein stone*. In the Wherry mine the lode, or Elvan course, was so rich in tin that it was named "stannified porphyry." At Wheal Unity the Elvan was so rich in tin as to be regarded as the tin lode. The Elvan course at Budnick carries at its side a small vein of tin.

Tin lodes are in general richer, or poorer, in Elvan than in the adjoining rocks in proportion to the hardness or softness of that rock. In Rosewall Hill, near St. Ives, where the Elvan was hard, the lode became poor. In Wheal Vor, near Helston, where the Elvan course was soft, the lode improved.

Copper lodes are generally as rich, and often richer in the *Elvan* than in the Slate or the Granite, as at Treskerby, Wheal Alfred, and Nangiles. At Tingtang the lodes were richest when between the Slate and the Elvan.

Elvan courses have been frequently considered as contemporaneous with their enclosing rocks, simply because they are traversed by metalliferous and other veins; but this only shows that the Elvan existed before the vein which passed through it, but when the vein passes by the side of or along the length of the Elvan course, they may probably be contemporaneous.

Elvan is sometimes found in floors, like the *dunstone* of Derbyshire,—as in Crumear and in Penberthy crofts, and in *bunches*, as in the United mines and Wheal Squire. There is no way of accounting for these bunches but the ejection of the plastic material, or by a separation while the *course of Elvan* was in a soft state, and its then getting surrounded with the alluvial Slate deposit.

Mr. J. Carne supposes Elvan courses to be true veins, and he argues in favour of their being of posterior formation to the adjoining rocks.

1. That they do not always underlie in the same direction, and scarcely ever at the same angle, as the dip of the Slate. The Elvan course at the Wherry mine underlies north; the Slate dips south-east. At Cligga Head the Elvan courses underlie northward, but the Slate dips rapidly towards the south.

2. In the copper mines of Tresavean and Treskerby the Elvan course is partly in Slate and partly in Granite.

3. Fragments of Slate are found in Elvan courses close to their walls (sides) or their junction with the Slate country.

4. The Elvan course in Polgooth mine, near St. Austell, *heaves* all the veins which it meets with, except a *flukan vein*, by which it is itself *heaved*.

The direction of *Elvan courses* is generally between east and west, and north-east and south-west; the average being, according to Henwood, about

twenty degrees south of west, several of them bearing some degrees to the northward of west. They more generally incline to the north than to the south, but in direction and dip they undergo many flexures.

The Elvan courses traverse Granite and Slate alike, but their character varies with that of the rocks through which they pass; and in the Slate series they vary more than they do in Granite. A spheroidal structure is common among Elvans, and large portions, which have no other distinguishable difference, often take this form, and are separated from the surrounding parts of the same rock by concentric bands of a ferruginous mineral, often decomposed into a clay.

Elvan courses have been worked in various places for metallic minerals. At *Wherry* mine, *Parbola*, *Relistian*, *Wheal Vor*, *Polberrow*, *Budnick*, *Wheal Coates*, *Polgooth*, and other mines the body of the *Elvan* has been removed for the tin ore found in it. Generally the Elvan has been penetrated by the tin, but at Wheal Vor, White Works, and at Polberrow, irregular and unconnected masses of tin ore were distributed through it.

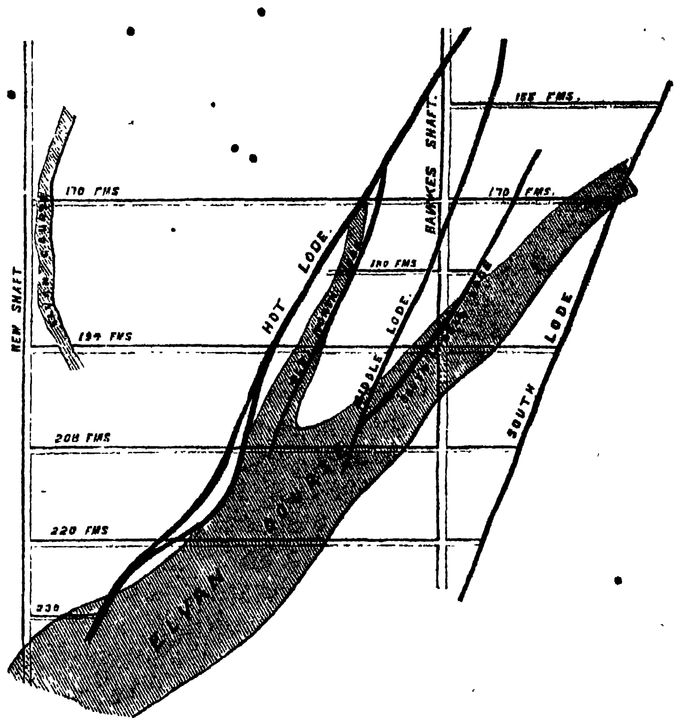


Fig. 22.—Elvan Course obliterating Lodes.

Elvan courses often intersect mineral lodes. Mr. Michael Williams gave it as a general law, especially in the Gwennap district, that a lode is seldom or never rich, after it has passed through an Elvan course in descending; and he gives as an example of this, the accompanying section of the lodes (Fig. 22) which pass into the great Elvan course of the United mines in Gwennap—where two of the lodes are lost in the Elvan at about 208 fathoms from the surface, and the great "Hot lode" is completely extinguished by it, at a little below the 230 fathoms.

Mr. Thomas,* on the contrary, states that copper lodes sometimes prove very productive in traversing a course of *soft* Elvan, which was particularly the case at Nangiles mine; but in courses of *hard* Elvan the lodes generally run very small and poor, and many lodes, particularly *tin* lodes, split into small branches.

* "Report on a Survey of the Mining District of Cornwall, from Chasewater to Camborne." By Mr. Thomas. 1819.

There is an established belief that the Elvan courses act favourably upon the mineral lodes running parallel with them—but we have no very satisfactory evidence in proof of this—and the question demands a very close investigation. It will be seen as we proceed, that the *Toadstone* of Derbyshire and the *Whinsill* of the northern counties present in some respects a close analogy of the Elvans of the western one. They are evidently igneous rocks, and they often appear to influence the productiveness of a mineral lode, and are themselves under some circumstances the bearers themselves of metalliferous ores. A remarkable example of the intrusion of Elvan courses amidst a set of most productive copper lodes is shown in the woodcut of a portion of the United mines in Gwennap (Fig. 20).

GREENSTONE, called also *Freestone* or *Irestone*, is thus described by Pryce: "It is by much the hardest of all strata, and borrows its name from its extreme hardness, and not because it contains iron. It is of a bluish colour, and usually so hard that it must be wrought with steel borers and then blown by gunpowder. It often keeps a course east and west like a lode, but is commonly very wide, and therefore it is very tedious and chargeable where an adit must be driven across through it. It is this stratum that is uppermost through great part of the middle of Camborne and Illogan parishes, where many principal copper mines are enclosed in it." In this Pryce is singularly wrong, as will be shown by the woodcut at p. 213, Fig. 23, which is copied from the Geological Survey Map of Cornwall.

This remarkable group of Greenstone rocks, extending from St. Erth, near Hayle, through Gwinnear up to near Camborne, requires some attention. Stretching from St. Erth in a north-easterly direction towards Camborne—as will be seen by studying this map—there occurs a remarkable series of Trapean or Greenstone rocks. This rock, which is extensively worked on account of its exceeding toughness, and broken as a stone for roads, is confined, or nearly so, to the Slate rocks. A large *Greenstone* course extends from Camborne through Tuckingmill to Treleigh (north of Redruth), at which places large blocks of stone are lying on the surface, and may be seen in the open pits at South Roskear mine. This course appears to hold a regular direction, often the same as the lodes. Three large courses of this rock run from St. Erth, through Gwinnear on towards Camborne, the direction taken being from south of west to the north of east. Similar masses are found appearing about midway between Marazion and Penzance observing the same direction, until at about a mile westward of the latter town the Greenstone suddenly curves to the southward, as if its flow had been intersected by the great westerly mass of Granite, and turns round to the east at Newlyn, and then taking a south-east course passes into the sea at Penlee Point, in the parish of St. Paul. No Greenstone appears between Penzance and the Land's End, but it forms the face of the cliff at Botallack Head in St. Just and the Gurnard's Head in Zennor. The picturesque character of the coast in St. Just and in Zennor is mainly due to the interstratification of the Greenstones and the Slaty rocks, and large masses occur at St. Ives. Mineral lodes are found abundantly in the Gwinnear and Camborne Greenstone districts (see Map). Very few indications

of veins of metalliferous minerals occur in the Penzance district, and not many in the Greenstones of St. Ives. Conybeare,* in his paper pointing out the general mineralogical difference between the rocks of North Devon and those of South Devon and Cornwall, divides those rocks into—

Metalliferous, or, more strictly speaking, cupriferous and stanniferous Slate, including various porphyritic and felspathic rocks (*elvans*), and occasionally *Greenstones*. This he terms the *inferior* Slate.

Slate which he terms *superior*, contains no Elvans, but abounds much more in *Greenstone*, especially its obscurer varieties. Conybeare continues his definition of the rocks in the Grauwacke series; but, as it is not intended

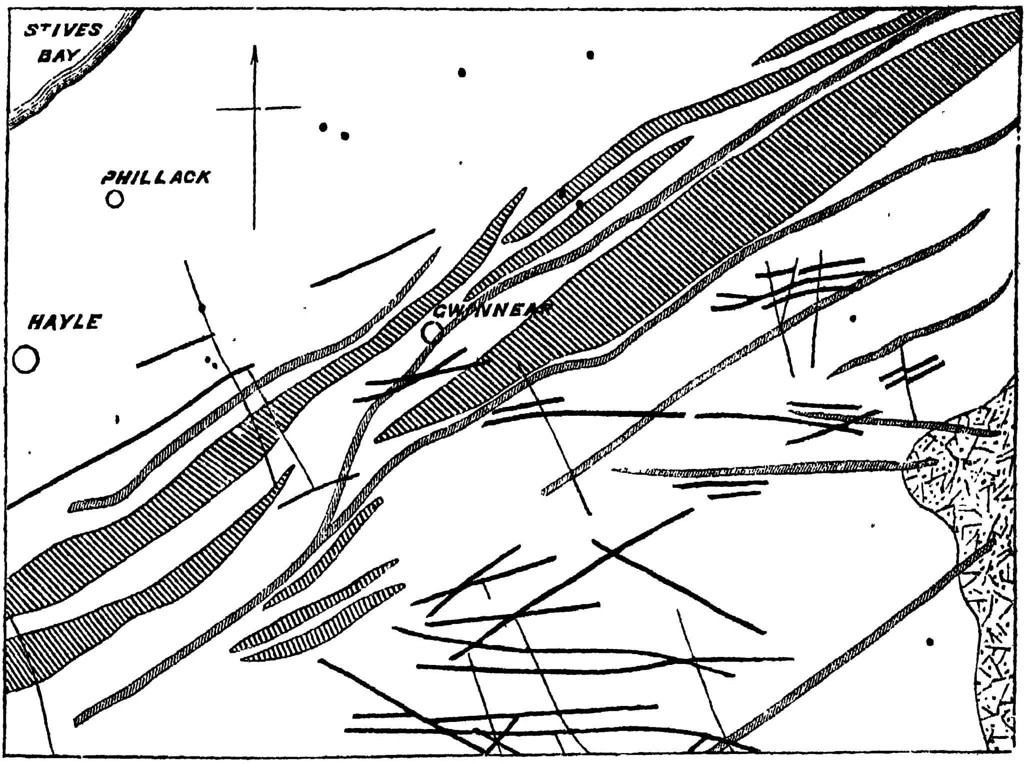


Fig. 23.—Greenstone Rocks from Hayle through Gwinnear.

that this treatise shall deal with geology beyond its connection with mining, it is not thought desirable to quote this geologist further.

The Trap or Greenstone rocks of Western England are usually intrusive in the Slate rocks or the ordinary "Killas" of Cornwall.

Dr. Boase † gives the following description of the Cornish Greenstones :—

"A basis of compact or granular felspar, variously combined with hornblende in different proportions, sometimes the one and sometimes the other

* Conybeare, "Memoranda relative to Clovelly." ("North Devon Geological Transactions," vol. iii.)
† "On the Geology of Cornwall." By Henry S. Boase, M.D. ("Transactions of the Royal Geological Society of Cornwall," vol. iv. 1832.

predominating in the mass. This rock when decomposed produces a reddish soil.

"*Sienetic Greenstone* occurs at Davidstow, near Polliphant.

"*Hornblendic Greenstone.*—St. Clear, Tolcarne, near Penzance.

"*Compact Greenstone.*—Treneere and around Penzance.

"*Lamellar Greenstone.*—Rosecradock, St. Clear, Botallack.

"*Schistose Greenstone.*—Adjoining all the last.

"*Argillaceous Greenstone.*—Liskeard.

"The compact and schistose Greenstones repeatedly pass into each other, so that in traversing them from the Granite they appear to alternate; but this does not hold good to any great extent in the length of their beds, as may be seen on the shores of the Mount's Bay, where the massive rocks are insulated in the body of the Slate. Greenstone often gradually passes into rocks which are for the most part soft and thick lamellar Slates of various shades of blue and green. They contain beds which are compact and earthy, differing only from the Slate in which they are imbedded in wanting the schistose structure, and they abound in metalliferous veins, the matrix of which is composed of quartz and dark grey crystalline chloride. The quartz is sometimes much intermixed with felspar; which, decomposing into a white clay, renders the whole of the lode friable."

It should be noticed that under the general term of Greenstone many different varieties of hornblendic rocks are included. Many of these formations around St. Just may be strictly said to be hornblendic. They are sometimes very compact but often slaty, and in the neighbourhood of Cape Cornwall we find curious alternations of purely hornblendic with slaty rocks. They contain in different parts (besides hornblende) quartz, felspar, chloride, and other minerals. So similar are they that even Mr. J. Carne, than whom there was no better observer of the Cornish rocks, says: "I have given the name of Slate to the whole, although they have of late frequently been called Greenstone. The Slaty rocks in general have a better title to the name of Greenstone Slate, or hornblende Slate, than to that of Clay-Slate. *Greenstone*, however, is a word whose application is becoming almost as general as that of Grauwacke was some years ago." *

It is not unusual to find in the small fissures of Greenstone thin layers of native copper. This has, on several occasions, led to a belief that copper ore might be found in quantity at depth, and several mining adventures have been the consequence. In the mass of Greenstone at Penolva, St. Ives, a shaft was sunk and an engine-house built; and again in the romantic rocks known as the Tower of Babel, on the western side of Porthmere Beach, and extending on to Clodgy Point, considerable mining operations have been carried on, but nothing of consequence has been found.

KILLAS or CLAY-SLATE.—This term is applied almost universally to the Slate rock found in the mining districts of Cornwall. Mr. Carne says, in a note to his paper on the mineral productions of St. Just: "Show a miner primite Clay-Slate or transition Slate, or micaceous Slate, or grauwacke Slate, or hornblende Slate, if it be not very hard, and he

* Carne, "On the Mineral Products of St. Just." ("Transactions of the Royal Geological Society of Cornwall," vol. ii. 1822.)

will call the whole *Killas*." The word was no doubt introduced into Cornwall by the German miners who settled in that country at the time of Queen Elizabeth, and who for a long period held possession of its tin mines and certainly worked a few copper mines.

Killas, which comprehends the whole of the district on the Geological Maps from Penzance to Davidstow on the north-east of Cornwall, and to Newton Bushell in Devonshire on the south, and which is coloured with the tint adopted for the New Red Sandstone, now called *Devonian*, is the natural stratum of the metalliferous beds of the West of England.

The definitions given by Pryce, "Of the Strata of the Earth," &c., are valuable as showing the ideas of the miners of his time (1778) of this peculiarly metalliferous rock *Killas*, or *Clay-Slate*. "Of Killas I have observed six sorts common to us, the white, the red, the yellow, the brown, the cinerous or bluish, and the deep blue. The first is very white and tender, and from its exceeding tenderness is called *Fair Ground*. It requires much timber and boards for binding and securing it from falling in the mine and endangering the workmen's lives. The red is not so fair, but is well disposed for copper or tin lodes, the latter preferably. The yellow is but indifferently disposed for either. The brown, which has various shades of lighter and deeper colours, is generally a hard stone, and contains lodes of tin more commonly than copper.

"But of all the Killas the cinereous or pale blue is most desirable as the enclosing stratum of a copper lode. We find it the most common and agreeable chest that encloses our cabinet of jewels. . . . . It is this kind of Killas which we call *Feasible ground*, *i.e.* to be easily broken, yet firm enough to stand without the support of binding with timber and boards.

"A Killas in its best state is soft, tender, fleshy, and fatty, which will cut to any form underground, and requires no timber; but if it is hard and untractable, and works in very small shreds of stone, it is unfavourable to work or enclose metal."

Werner, in 1793, examined a series of specimens from Cornwall, and he expressed no doubt that the metalliferous rock of that county, the Killas, was a genuine *thon-schiefer* or argillaceous Slate, differing in no respect from that which occurs in Saxony.

In Cornwall the term Killas is applied to every member of the Slate series, indeed to every rock which the miners cannot identify as Granite or Elvan. Mr. Henwood says: "It is therefore evident that this name is applied to rocks of very different characters; as, for example, to the hornblende Slates and Greenstones of St. Just and St. Ives, as well as to the Clay-Slates of Gwennap, St. Agnes, and St. Austell. The St. Just and St. Ives Killas would generally be known in other districts by the designation of *Iron* or *Ire stone*." Experience of many years and considerable familiarity with the miners of the districts named, lead to a conviction that the Greenstones were never called Killas by them; it is possible that the hornblendic Slates may have been so. The term of *Ire-stone* has been constantly applied to the Greenstones in all parts of Cornwall.

When near the surface it is usually of a light brown colour and in some places nearly white; at a certain depth from the surface it becomes full of

veins of quartz, and at a greater depth it acquires greater uniformity, becomes much harder, and is generally of a blue colour. It is generally regularly stratified at various degrees of inclination. Some of the Killas is in very hard irregular masses. The section given in the adjoining woodcut, Fig. 24, is taken from Trevaunance beach, St. Agnes, where we have a very fine example of those three varieties of Clay-Slate. If an observer carefully trace these beds from the point indicated, along the coast passing north-eastward, he will find that the lower, the blue bed, gradually becomes converted into cleavable Slate,—until at Newquay some of the Slate rock of that district is actually used for roofing slate; and farther east, at Delabole, we find one of the oldest—and most celebrated—Slate quarries in the county. Many similar beds varying in quality and character are worked near the well-known Tintagel Castle.

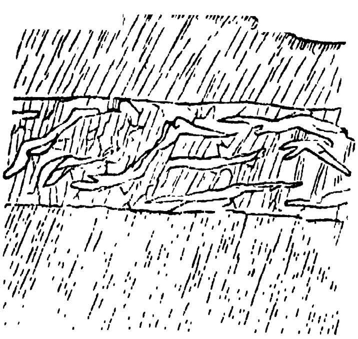


Fig. 24.—Section of Strata.

In many cases immediately under the soil there appears a compact stratum of quartz stones two or three inches in thickness (nearly all those quartz beds have, however, disappeared, and been used as a road material); under this is a clayey loam of a yellowish colour, about two feet in depth, resting upon the Killas or upper bed, the superior part of which is generally in a decomposed or disintegrated state, broken into small pieces, but becoming firmer as the depth increases. This is the second bed shown, and is the original source of the quartz stones.

The Killas gathers around the great Granite bosses of the county in

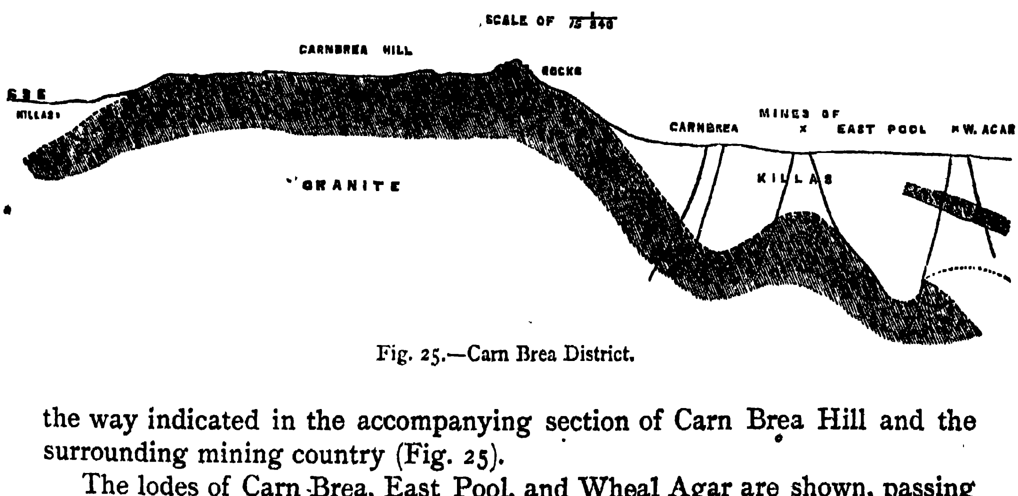


Fig. 25.—Carn Brea District.

the way indicated in the accompanying section of Carn Brea Hill and the surrounding mining country (Fig. 25).

The lodes of Carn Brea, East Pool, and Wheal Agar are shown, passing from the Killas into the Granite; the true dips of these lodes being indicated.

Grauwacke is a Saxon miner's term, and has been applied to a rock

formation which constitutes the greater portion of that group of mountains known as the Hartz. Werner supposes this rock to have been deposited during the passage or transition period of the earth from a chaotic to its habitable state. This appears to be a very loose and unsatisfactory hypothesis. Can we draw a line of any description, between the chaos and that order which prevailed when man was supposed to appear on the Earth? Jameson says grauwacke commences a new geognostic period, namely, that of mechanical deposition. Mr. Hawkins, in discussing the value of this name, says:—

"It is now pretty generally acknowledged that the terms 'grauwacke Slate' and 'argillaceous Slate' are convertible, it being impossible without the aid of petrifaction to ascertain where the one ends and the other begins.

"A dilemma so unfortunate as this ought to have suggested the probability of some error in the process of reasoning upon which these distinctions are founded, and might sooner have led to its correction. . . . . It is surprising, as the derivative origin of the grauwacke rests so much upon this view of the subject, that there should ever have been any other opinion in respect to this order, and that the grauwacke rock, instead of terminating the formation of argillaceous Slate, should have been regarded as its archetype, or the point from which it proceeded."

So general is this misconception that the terms "grauwacke" and "grauwacke Slate" have been applied without reserve to strata which exhibit in a very imperfect manner the derivative character—a primitive rock, indeed, differing in no respect from the argillaceous Slate. The consequence of which is, that the denomination of grauwacke in the literal sense of the word has become nearly obsolete.

De la Beche, who examined these rocks with great care, says:—

"In the grauwacke and carboniferous series of this district we find silicious grains, generally of quartz, cemented by matter which closely approaches chalcedony or chert, much intermingled with peroxide of iron in the Red Sandstone of these rocks. In the Red Sandstone series the cohesion is considerable, and we find the cementing substance chiefly consisting of alumina, peroxide of iron, and the red oxide of manganese, the rock being harder when calcareous matter forms any considerable portion of the cement." *

SERPENTINE, DIALAGE, TALC SCHIST.—Serpentine rock, which is especially well shown at Kynance Cove and in the Lizard district, is one of the most ornamental stones of Great Britain. It has a basis of magnesia, and derives its colour from salts of chromium and iron. The Lizard district is made up of hornblendic Slate, Serpentine, Dialage rock, and altered Devonian. These run closely into each other, and are often not easily distinguished. Dr. Boase remarks: "The Hornblende Slate of the Lizard is entirely distinct from that of the other parts of Cornwall, and therefore ought to be separated therefrom. . . . . The transition of this Slate into Euphotide and Serpentine has been often noticed; but it is more closely allied to the former, as is shown by its great hardness and by its resplendent lustre.

* "Report on the Geology of Cornwall, Devon, and West Somerset." By Henry T. de la Beche, F.R.S., &c. Longman. 1839.

This schist appears sometimes to be embedded both in Euphotide and in Serpentine, and at other times the latter rock seems to be subordinate to the schist; but the fact is that all these, although they alternate on a given line, yet do not long continue parallel, but they mutually abut against each other; sometimes the one and sometimes the other prevails. Serpentine exhibits a great many varieties, some of which are very hard, whilst others are so soft as to yield to the nail. This difference appears to depend on the felspar base, which undergoes several modifications between a crystalline, compact, and granular state, as seen in the precious Serpentines in the indurated *steatites*, and in the common and ollareous Serpentines." Serpentine is also found at Clicker Tor, near Liskeard. The Polliphant stone is a variety of this rock or of Elvan. Serpentine must not be regarded as strictly a metal-bearing rock, but few examples of any mineral ores having been found within it. The magnesian rocks are rarely metalliferous. Lead containing silver and copper ore and manganese has been found occasionally, but in small quantities only.

It is not unusual to find in the fissures of the Serpentine rocks masses of native copper; these have frequently induced a further search for mineral treasure, which has never proved very successful. In Trenance mine deposits of a promising character were found in 1852, and consequently it was hoped that a profitable copper mine might have been opened out. This hope was, however, not realised, and the mine was abandoned about 1854. The fine specimen in the *Museum of Practical Geology*—which was presented by the Adventurers—is only a portion of the mass as it occurred in nature, the miners being compelled to break it to raise it to the surface. The original piece was upwards of a ton weight.

The Serpentine is frequently crossed by veins of steatite, which was found in such quantities near Mullion, that, under the name of *Soap-stone*, it was sent in considerable quantities to Bristol, and used in the manufacture of porcelain.

It appears that this may be the most suitable place to introduce a few remarks on the formation of rock masses in general, more especially of those which have evidently been formed from alluvial deposits. The slow and silent processes which have been at work through countless ages, producing a roofing-slate and probably most of the lithological phenomena which we have to consider, demand a careful study. Our information is exceedingly limited, but such as we possess will be found to bear very importantly on the phenomena which form the chief subject of our consideration.

If we consider the condition of finely-comminuted sand accumulated in large quantities, we feel that with moisture, cohesion of the particles may speedily be brought about, but that in a perfectly dry state this can only be effected by the prolonged action of cohesive force. Mechanical force, artificially applied, has been found to be sufficient to produce the coherence of finely-comminuted china-clay in a dry state, but the degree of consolidation required for the uses to which the compressed clay is put, can only be obtained by the subsequent action of fire. In the Potteries this process is largely employed in the production of various pieces of earthenware.

Where moisture is present we can scarcely conceive finely-divided detritus existing long without some agglutination ensuing. The alkaline constituents of nearly all rocks are soluble to a greater or less degree, and the water holding them, passing slowly through the masses, affords the cementing materials required. In Granite, Slate, or Elvan, their hardest portions are almost invariably rendered so by quartz, or some form of silica. These indurated portions are found invariably to be unfitted for the presence of metallic minerals. Where lodes penetrate these hard portions of rock they are usually small, and their contents differ but little from the surrounding mass. Supposing that the mineral ores found in the fissures are the result of infiltration, it can be easily understood that those indurated parts would present obstacles to this process.

Into beds through which water percolates, soluble matter derived from other rocks may be introduced, and, combining with the constituents, form new compounds. When these conditions are maintained, especially beneath the surface of the sea, the saline constituents are subjected by the process of infiltration to a mechanical separation. It has been shown by Dr. Hoffman and Mr. Witt,* that the waters of the Thames, filtered through well-constructed filtering-beds, lost a considerable portion of the salts held in solution; and Dr. Normandy † proved that sea water was deprived of all its salt, by being forced through fifteen feet of sand, or powdered glass. Here we have evidence of the agent required as the cementing material for the detrital matter out of which the rock masses are often formed.

Several observers have drawn attention to the influence of hot springs, coming in all probability from great depths, charged with silica in solution, and depositing minute quantities of gold and other metals.

Mr. John Arthur Phillips has described with much precision the process of evaporation going on as these thermic waters approach the surface, and the deposition of masses of silica and other salts with particles of the metals, especially of gold, amongst them.‡

In each class of rocks we find variations in the prevailing conditions. In Sandstones we find the cohesion of the grains of sand very unequal. In some the cementing matter is as hard as the grains themselves; in others it is weak, and the rock is friable.

In the Clay-Slate and in the carboniferous series of Cornwall and Devonshire there are very marked differences in the conditions prevailing in the metalliferous and non-metalliferous rocks.

The percolations of silica, in one of its conditions—in solutions through the rocks—often combined with alumina, lime, and alkalies, will no doubt account for the unequal consolidation of the Sandstones and Slates.

The consolidation of mud and clay into Slates is due to causes akin to those which converted the sands into hard bodies. All these examples of cohesion probably occurred—at all events were considerably advanced—before the deposits suffered any considerable disturbance. Even in a state of repose, it is evident that certain chemical changes were in progress, and

[* ... M]etropolitan Drainage, by Dr. Hoffman and Mr. Witt.

† Normandy. [... se]e "Ure's Dictionary," art. Sea Water.

‡ See "On the composition and Origin of the Waters of a Salt Spring in Huel Seton Mine." By J. Arthur Phillips, F.R.S. ("Philosophical Magazine," July, 1873.)

that crystalline forces were in action, bringing together particles chemically the same, which gradually assumed a geometric form. The power of bodies to crystallise freely is shown by the cubes of iron pyrites in some of the Slates, and the crystallization of quartz in some other rocks. Especially the double-headed crystals of quartz, commonly called St. Agnes Hail, found beautifully perfect in the Wheal Coates Granite, are examples of this. The solution of silica flowed steadily through the sand or mud in dendroidal films; as the flint consolidated it exerted an enormous pressure, and thus increased the filmy passage, and formed a small fissure, in which, with yet more force, the same action proceeded. Small cracks were thus produced, and increased in size, spreading in various directions, producing eventually a system of quartz veins, spreading in an excursive manner through the mass. These evidences show that the sedimentary deposits have suffered considerable modifications in the condition of their component parts, since they were first accumulated. That they have been subjected to mechanical forces of an extreme kind is evident by the violent contortions discovered in those beds, which were at one time nearly horizontal, but which are now placed at very varied angles, and in some isolated cases they have evidently been turned over. This is singularly shown in the rocks around Boscastle and other places in the north of Cornwall.

The uplifting forces are usually referred to the expansion of the deeper rocks, under the influence of subterranean heat. This is not a place to enter into any examination of the hypothesis of central heat, or of the existence of a fused mass of matter beneath the consolidated rocks, to which man has penetrated. Regarding the question especially as it respects the Granite rocks as an unsettled one, the hypothesis is accepted so far as it supports the view, that the Granitic masses have forced themselves through the deposited beds in a state of, probably, igneous fusion, and have thus produced disturbances of several kinds. For example, the consolidated beds have been rended by the force applied, and fissures of varied sizes and depths have been the result. The heated mass being kept for some time in contact with the deposited rocks would effect these changes, which are regarded as metamorphoses, and alter the chemical constitution of the Slates and Sandstones.

When Greenstones, Basalts, and the like igneous masses have been thrust through, we find that the fissures produced by the more intensely-heated fluid masses are filled in with the matter which constitutes that which forms the primitive dyke.

At the same time, water converted into vapour would be introduced under pressure, and combine with the substances originally present in the sedimentary deposits, and produce many mineral compounds different from those existing in the detrital beds.

Professor Hausmann states that the Clay-Slate which was used in constructing a blast furnace at Mägdesprung, in the Anhalt territory, had, from the long operation of heat without becoming fluid, acquired an aspect like silicious Slate—in appearance very much resembling the rock which is found in the vicinity of Greenstone, where that rock is in contact with Clay-Slate. The same author notices the crystallization of oxide of zinc in

iron furnaces, sometimes accompanied by salts of potassium and sulphides of lead in the walls of smelting furnaces.*

De la Beche writes: "It would be uselessly occupying time to attempt a description of all the altered rocks which occur in Cornwall, inasmuch as the varieties are as considerable as the composition of the rocks brought together under the necessary conditions. The Slates not unfrequently become hard and of a dark colour; dark purple is by no means an uncommon tint. Another common variety consists of a glossy grey Slate, often containing disseminated and imperfect crystals of a mineral resembling chiastolite.

"The coast from St. Ives to Penzance affords a good opportunity of studying the alteration of fine-grained Greenstones and ordinary grauwacke Slates, portions of these rocks occurring on the outskirts of the Land's End Granite in a manner to render the junction of the two classes of rocks very accessible."†

Dr. Forbes has carefully studied the mineralogical character of rocks forming the mining district from St. Ives to the Land's End.‡ Veins of actinolite, he points out, are very common among the Greenstones of this coast, and veins of schorl are also found among the same rocks at St. Ives. Schorl is a mineral which may be decomposed in one place and, under favourable conditions, recomposed in another. We have evidence in the schorl rocks of Trevalgan, near St. Ives, and at Rosemerrin, near Morvah. Schorl may be observed between, and approaching the joints of the Granite, in many places, as at Castle Trereen (the Logan Rock) and Peden-maen-anmear. Radiated nests of schorl in the Granite are common in many places where that mineral is abundant, especially in the rocks in the vicinity of Wicca Cove, near Zennor. Schorlaceous Slates are also found in Castle-an-Dinas and other places. De la Beche says: "We may suppose the schorl to have been introduced amongst the ordinary grauwacke Slates, of which they constitute a continuous part subsequently to the intrusion of the adjoining schorlaceous Granites. The mica also in many cases appears to have been formed in the altered rock from matter received from the adjoining Granite, more particularly when the Granite is very micaceous; and felspar in the gneiss-like variety may have been often added in the same manner. That these minerals may have been introduced is rendered far from improbable from the artificial formation of minerals resembling mica and felspar."

The condensation of vapours and the formation of mineral substances under their influence have been already referred to. These phenomena should be examined in connection with the changes which are observable in rocks, which are traceable to heat derived from the intrusion of rocks of high temperature. It is not unusual to find native copper in the minute cracks formed in the Greenstone rocks themselves. Examples, as we have already stated, may be observed at Penolva, St. Ives, where the occurrence of those strings of metallic copper led to the sinking of a shaft. At several places in the Hornblendic and Serpentine rocks of the Lizard, and in many of the Greenstone masses, for example, native copper has been observed in the

* Hausmann, "On Metallurgical Phenomena as illustrative of Geology." (Jameson's "Edinburgh New Philosophical Journal," January, 1838.)

† De la Beche, "Geology of Devon and Cornwall."

‡ "Transactions of the Geological Society of Cornwall," vol. ii. p. 260.

Greenstone quarries worked near Flushing, on the banks of Falmouth Harbour, and in the neighbourhood of Penryn, extending towards Pons-an-Nooth Valley, where some curious mineralogical phenomena may be observed.

The bearing of this may not be evident at first to the superficial observer, but the influence of dissimilar rocks on the conditions of the mineral veins is, to a considerable extent, explained by the phenomena under consideration. By the influence of atmospheric changes, by the action of water, associated by the powerful effects of heated masses, rocks have been finely comminuted and transported from the parent rock. These have been formed into clay, which has afterwards been converted into Slates by the influence of electric currents, or mechanical pressure, during those changes. Divisional planes have been produced and fractures formed which have subsequently presented the conditions of mineral veins. Mechanical pressure has been shown by Professor Tyndall to produce lamination; heat we have seen will do so, and electric currents will give rise to a similar structure.

That the process of lamination might be commenced in moist clay by the action of electricity was first shown by Mr. R. W. Fox.* He considers—from his well-conducted experiments—that the general laminative condition of the clay appeared to indicate that a series of voltaic poles were produced throughout the clay, the symmetrical arrangement of which had a corresponding effect on the structure of the clay, and that this view was confirmed by the occurrence in several instances of veins, or rather laminæ, of oxide of iron or oxide of copper, according to the manner in which those experiments were conducted. Mr. Fox points out the bearing of his experiments upon the cleavage or lamination planes of rocks, and "considers the prevailing directions of electrical forces, depending often on local causes, to have determined that of cleavage, and the more or less heterogeneous nature of the rock to have modified the extent of their influence."

The problem relating to the influence of weak electric currents in determining the lamination of clay was determined by the author in 1848. Adopting the method of experiment adopted by Mr. Fox, I fitted up a square *vessel* with a zinc plate, and one of copper, each 14 inches long by 8 inches wide, against two of its sides; these were connected by an arch of thick copper about 18 inches long. When this vessel was filled with water a voltaic circuit was completed, and from the chemical actions induced, a weak electrical excitement ensued.

This arrangement may be imagined to represent a natural basin, in which certain electrical conditions prevail. A mass, weighing 10 lbs., of Stourbridge clay was placed on an inclined plane, and by water dropping from a cistern, supplied with water from the well in Trafalgar Square, it was very slowly carried into the trough in a state of fine division, and gradually deposited in the water according to the law of gravitation, and under the influence of such forces as may be excited during the period of subsidence, it being, in this experiment, the force of voltaic electricity. It required ten months to wash down the mass of clay and to deposit it between the plates. The deposition being complete, the flow of water was stopped and the fluid

* See "Reports of the Royal Cornwall Polytechnic Society" for 1836–37, &c.

allowed to evaporate at the atmospheric temperature. This occupied four months more. Another period of three months was spent in drying the clay so as to admit of its removal in a solid mass. Thus the experiment was altogether continued over a period of seventeen months. When carefully broken the section exhibited several remarkable peculiarities. The first feature to be noticed is one which has been observed to a greater or less extent in every experiment made, and the experiments, under various conditions, have been several times repeated. The woodcut, Fig. 26, will assist the description.

The water carrying the clay flowed in on the zinc side Z, consequently there was a natural tendency to heap up on that side rather than on the copper side C. There was always shown a tendency to form curved lines, opposed to the influence of gravity, as the particles approached the copper plate; these curved beds are indicated by the italic letters *a*, *d*, *f*.

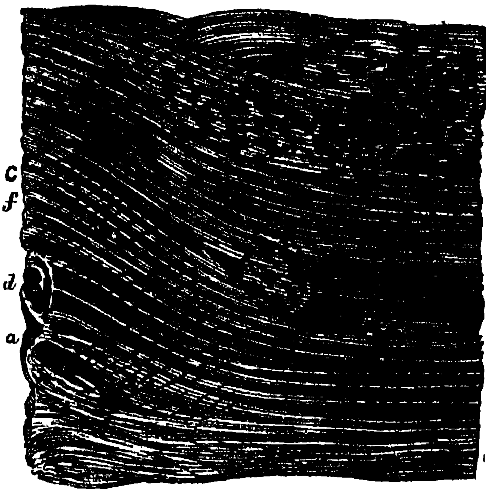


Fig. 26.—Lamination of Clay by Electricity.

Had this been observed in one instance only it would not have deserved attention; but when we find the same thing occurring in perfectly still water, and always on the side next the copper plate, it becomes instructive, clearly proving the tendency of minute particles of matter to arrange themselves in obedience to the directions of electric currents.

The lines of bedding were always more or less curved lines, the alterations in the thickness of the beds being occasioned by irregularities in the flow of the water, and on several occasions an actual cessation of the flow. As shown in the woodcut at 1, 2, 3, numerous fine lines were seen running across the beds. These lines were marked most distinctly on the mass when first broken, and formed cleavage planes cutting through the stratified beds—thus imitating, on a small scale, many of the phenomena of lamination and cleavage as exhibited by rocks in nature.

Dr. Berger, in 1811, observed that the grauwacke of the cliffs of Whitesand Bay, near Millbrook, Cornwall, separated into "very regular rhomboidal joints."* Professor Sedgwick observed of Devon and Cornwall: "Whenever any natural section of the country exposes an extended surface of the Granite, we find portions of it divided by fissures, which often for a considerable extent preserve an exact parallelism among themselves." And again: "These masses are not unfrequently subdivided by a second system of fissures nearly perpendicular to the former, in consequence of which structures the whole aggregate becomes separated into blocks of rhomboidal form."†

The late Mr. J. S. Enys, of Enys, observed, in 1833, that the vertical divi-

* "Geological Transactions," vol. i. † "Cambridge Philosophical Transactions," vol. i.

sional planes or joints of the Granite near Penryn took a general direction from N.N.W. to S.S.E., varying but a few degrees from those points. Sir Henry de la Beche wrote, in 1834: "The cleavage of the Devon and Cornwall Granite is frequently in given directions over considerable areas, showing that the causes producing it have acted on the large scale. . . . . The Granite on the northern part of Dartmoor was not only cleaved perpendicularly in the direction N.N.W. to S.S.E., but also in lines at right angles, or nearly so, to it." *

No man ever observed the geological structure of a country with the close exactness of De la Beche. The advance of practical geology to its true position as a science is mainly due to him. Commencing, at his own cost, the Geological Survey of Cornwall, which, with its mines and mineral formations, presented numerous most complicated phenomena, he, single-handed, with vast industry did the work of many men, and in his book on Devon and Cornwall he has left an imperishable memorial. From this work originated the Geological Survey of the United Kingdom—which has been carried on with surprising exactness—and the Museum of Practical Geology, which preserves examples of all the rocks and minerals of our country, and enables every one to become acquainted with the important "sermons in stones." In addition to these, the *Mining Record Office*, over which the author has presided for thirty-eight years, was organised mainly through the same influence.

The informations given by De la Beche are so much to the purpose that we give his own words. Speaking of cleavage and the like he says:—

"Though the general direction of these lines,† which may be termed great divisional planes, to distinguish them from the cleavage lamination to be presently noticed, may be N.N.W. and S.S.E., varying only a few degrees from those points, these planes are by no means confined to it; on the contrary, there are many exceptions to it in the Granite districts of Cornwall and Devon. To show an average amount of local variation in this respect, we will select the coast between Peden-maen-du and Peden-maen-anmear, which includes the Land's End, as it is easily visited and the great divisional planes well seen. Commencing with the north, they run as follows:—

"At Peden-maen-du	325°
Near Carn Clog	325° and 242°
Near Carn Creis	318°
Nanjisal, or Mill Bay	316°
Carn Barra	318°
Carn Mellyn	328°
Tol-Peden-Penwith	316° and 218°
On west of Porth Chapel	328° and 225°
Peden-maen-anmear	320°

"Taking the present magnetic north to be about 335° at the Land's End, the leading great cleavage of Peden-maen-du and Carn Clog would differ from it 10°; that of Carn Creis and Carn Barra, 17°; that of Mill Bay and Tol-Peden-Penwith, 19°; that of Carn Mellyn and Porth Chapel, 7°; and that of Peden-maen-anmear, 15°; the average of the whole differing from it between 13° and 14°. It will be observed that the cross great cleavage is not always sufficiently well characterised to be noticed, and that it varies more

* "Researches in Theoretical Geology." † De la Beche, "Geology of Cornwall," pp. 271–73.

considerably than the north and south cleavage, the cross cleavage planes at Carn Clog and Tol-Peden-Penwith differing 24° in direction. The line of cross cleavage makes an angle of 83° with the main cleavage at Carn Clog, of 98° at Tol-Peden-Penwith, and of 103° near Porth Chapel, the angle being measured on the west. The above will convey a fair idea of the general variations in the directions of the great divisional planes of the Granite in Cornwall and Devon, the results of many hundred observations on which would give 80 per cent. of instances in which the great divisional planes differed only 14° from the present magnetic meridian in the district, and about 15 per cent. of cases in which they differed between 14° and 20°, leaving about 5 per cent. of instances in which the north and south lines approximate the cross planes. The same numbers may be nearly taken to represent the proportion of cases in which the latter approximate to within a few degrees of a right angle to the other main planes.

"While a large proportion of the great divisional planes in the Serpentine of the Lizard have a direction approaching the present magnetic meridian, we find several exceptions to it. The following will serve to show the prevailing direction in the Serpentine of different parts of that district:—

Henscarth Rock (Mullion) . .	335° and 225°
Mullion Cove (south side) . .	355°
Between Vellan Head and Gue Graze	335° and 230°
Rill Head	295°
On north of Kynance Cove . .	340°
Lankidden Cove	290° and 211°
Black Head	287° and 197°
Porthbeer Cove	312° and 198°
Goonhilly Downs (north of Trelowarren) .	335°

"It will be observed that while the prevailing direction, with the exception of the local variations at Rill Head and on the south side of Mullion, is in, or within a few degrees of, the magnetic meridian from Kynance Cove to Goonhilly Downs; the main divisional planes between Kennack and Coverack Coves differ between 23° to 48° from it. While on the subject of the Lizard, it may be observed that the great divisional planes which traverse the hornblende Slate in it do not appear to have any strongly-marked and prevailing direction throughout. Near the lighthouses they hold a course of 263°, and somewhat farther west, towards Penolver Point, one of 322°. Perhaps, as a whole, the divisional planes of the hornblende Slate are more frequently within a few degrees of true east and west than in other directions. At Porthalla they have a direction of about 268°."

It appears necessary, to enable the student to follow the reasoning of the several hypotheses given of the conditions under which the mineral lodes have been filled with metallic ores, that the chemical constitutions of the rocks enclosing the veins should be known.

Many analyses have been made from time to time by chemists, who have established their names for reliability in investigations of this nature, which agree in the main.

Many philosophers, especially such as have a leaning towards chemical phenomena, have supported the hypothesis that the metallic minerals have been derived from the rocks in which the lodes are enclosed. They suppose that water percolating slowly through the rocks carried into the fissures in

solution the metals found. This, of course, involves the necessity of the existence of the metals, in a diffused state, in the rocks. This is not improbable. It must be borne in mind, however, that hitherto the chemical analyses have not afforded the evidence necessary to support this view. It should be remembered that none of the analyses have been made with a view to the detection of minute quantities of metallic matter; to do this they should have been made on a much larger scale than they have been.

The analyses of Killas, Granite, Elvan, and Greenstone which are given, were all made by Mr. J. A. Phillips, and were published by that gentleman in his paper on "The Rocks of the Mining Districts of Cornwall and their Relations to Metalliferous Deposits," read before the Geological Society of London.* These have been chosen as being the most recent, and therefore they have the advantages of all the improvements which have been introduced into modern chemistry. The examples analysed have all been selected by Mr. Phillips himself, with the especial purpose of learning if the rock conditions afforded evidences of the processes involved in its formation.

Especially are these more valuable than any others, since for many years Mr. Phillips has devoted his powers of observation to the phenomena of mineral deposits in all parts of the world, and under very varied conditions.† It must not be forgotten these analyses were made with a view to determine the lithological character of the rocks, and not to ascertain their mineral constituents. The German chemists appear to have found minute quantities of the metals in most of the rocks examined.

KILLAS—CLAY-SLATE.

TABLE SHOWING THE CHEMICAL COMPOSITION OF SEVEN VARIETIES OF CORNISH ROCKS.

—	I.	II.	III.	IV.	V.	VI.	VII.
Water { hygrometric	1·00	2·00	·35	·48	·39	4·12	·94
Water { combined	3·09	1·26	5·81	·67	2·74	6·97	2·18
Silica	60·42	50·92	53·30	67·32	40·22	32·98	67·82
Phosphoric anhydride	—	—	trace	—	·66	trace	—
Titanic	·21	trace	trace	·13	·15	trace	—
Alumina	20·84	20·79	21·73	20·85	24·01	16·73	9·56
Ferrous oxide	1·89	4·92	4·28	1·66	11·27	13·71	5·02
Ferric "	8·17	13·41	6·01	2·83	4·21	7·03	trace
Ferric persulphide	—	—	—	—	S. trace	S. trace	·68
Manganous oxide	·39	trace	—	—	—	—	1·20
Lime	1·71	1·62	trace	2·03	4·11	4·90	2·58
Magnesia	trace	—	·75	trace	6·52	11·52	3·42
Potassa	·77	·93	2·92	·60	1·67	·72	2·37
Soda	1·55	4·08	4·20	3·37	3·57	·63	4·32
	100·04	99·93	99·35	99·94	99·52	99·31	100·09
Specific gravity	2·60	2·73	2·52	2·71	2·95	2·82	2·73

Nos. I. and II. are examples of Killas from Polgooth mine, near St. Austell; the first specimen of rock being taken from above the adit, the second from the 100-fathom level.
No. III. is Killas from "Sanctuaries," St. Austell.
No. IV. from the 215-fathom level at Dolcoath.
No. V. is from Botallack, St. Just. Surface near the lode.
No. VI. is from the 130-fathom level, Botallack.
No. VII. from Wheal Seton, Camborne; taken from the 160-fathom level.

* "Quarterly Journal of the Geological Society" for August, 1873.

† It is interesting to know that Mr. J. A. Phillips has been for some time engaged on a work on "Ore Deposits"—a subject which his large experience enables him to treat more thoroughly than almost any other man.

GRANITE.

TABLE SHOWING THE COMPOSITION OF THREE VARIETIES OF CORNISH GRANITE.

—	I.	II.	III.
Water { hygrometric	·34	·87	·33
Water { combined	·89	trace	·89
Silica	74·69	74·54	70·65
Alumina	16·21	14·86	16·16
Ferrous oxide	1·16	·23	·52
Ferric ,,	trace	2·53	1·53
Manganous oxide	·58	trace	trace
Lime	·28	·29	·55
Magnesia	·48	trace	trace
Potassa	3·64	3·73	8·66
Soda	1·18	3·49	·54
Lithia	·10	trace	—
	99·55	100·54	99·83
Specific gravity	2·64	2·66	2·62

No. I. from Carn Brae Hill, Redruth.
No. II. from Botallack mine.
No. III. from Chywoon, Morvah.

ELVAN.

TABLE SHOWING THE COMPOSITION OF FOUR VARIETIES OF CORNISH ELVAN.

—	I.	II.	III.	IV.
Water { hygrometric	·11	·26	·43	·34
Water { combined	·49	2·03	1·27	6·11
Silica	72·51	72·82	71·46	47·35
Alumina	13·31	15·12	15·38	20·60
Ferrous oxide	3·87	trace	2·27	1·60
Ferric ,,	trace	1·75	·30	3·10
Manganous oxide	·62	trace	trace	trace
Lime	·60	·52	·47	4·72
Magnesia oxide	1·52	1·06	·22	6·12
Potassa	6·65	6·25	5·51	6·29
Soda	0·43	·51	2·79	3·58
Fluorine	trace	—	—	trace
	100·11	100·32	100·10	99·81
Specific gravity	2·62	2·64	2·65	2·70

No. I. Coarse-grained and highly porphyritic.
No. II. Much less coarse in grain.
No. III. As compact as chert, and with a conchoidal fracture.
No. IV. Contains an unusual amount of brown mica, and in other respects differs materially from ordinary Elvan.

GREENSTONES.

FROM NEAR THE VILLAGE OF TRELILL, ST. KEW.

		Mean.
Proportion of carbonate to rock—carbonates	. . . . .	25·73
rock	. . . . .	74·27
		100·00
The carbonates are composed of—carbonate of calcium	. . .	96·20
,, magnesium	. . .	3·80
		100·00

The percentage composition—deduction being made of the carbonates—is as follows:

	I.	II.
Water { hygrometric	·92	·93
Water { combined	4·38	4·58
Silica	48·66	48·37
Phosphoric anhydride	trace	trace
Alumina	23·27	22·92
Ferrous oxide	13·12	13·03
Ferric "	·77	1·01
Manganous oxide	trace	trace
Magnesia	3·20	3·18
Potassa	·57	·63
Soda	5·17	5·22
	100·06	99·87

FROM BOTALLACK (I.) AND LEVANT MINE (II.).

	I.	II.
Water { hygrometric	·21	·20
Water { combined	·24	·22
Silica	47·90	48·10
Alumina	19·26	19·37
Ferrous oxide	7·55	7·79
Ferric "	1·67	1·42
Manganous oxide	trace	trace
Lime	10·57	10·51
Magnesia	7·97	7·56
Potassa	·49	·42
Soda	4·33	4·07
	100·19	99·66

In "Researches in Physical Geography," published in the "Transactions of the Cambridge Philosophical Society" by Mr. Hopkins, we find some speculations upon the action of the forces, to which the uplifting of large masses of the Earth's crust is due; and as these remarks bear on the lines of fracture—the fissures or rents, which became eventually *mineral veins*—they demand attention. The author says, with respect to the action of an elevating force: "I assume this force to act under portions of the Earth's crust of considerable extent, at any assignable depth, either with uniform intensity at every point, or in some cases, with a somewhat greater intensity at particular points; as, for instance, at points along the line of maximum elevation of an elevated range, or at other points where the actual phenomena seem to indicate a more than ordinary energy of this subterranean action. I suppose this elevatory force, whatever may be its origin, to act upon the lower surface of the uplifted mass through the medium of some fluid which may be conceived to be an elastic vapour, or in other cases a mass of matter in a state of fusion from heat.

"The first effect of our elevatory force will, of course, be to raise the mass under which it acts, and to place it in a state of *extension*, and consequently of *tension*. The increased intensity of the elevatory force might be so rapid as to give it the character of an impulsive force, in which case it would be impossible to calculate the dislocating effects of it." He further supposes "this intensity and that of the consequent tensions to increase *continuously*, till the tension becomes sufficient to rupture the mass, thus producing fissures and dislocations." Treating of the nature and position of such dislocations, he says: "These will depend partly on the elevatory force, and partly on the resistance opposed to its action by the cohesive power of the mass. Our hypotheses respecting the constitution of the elevated mass are

by no means restricted to that of perfect homogeneity; on the contrary, it will be seen that its cohesive power may vary in general, according to any continuous law, and, moreover, that this power, in descending along any vertical line, may vary according to any discontinuous law, so that the truth of our general results will be independent, for example, of any want of cohesion between contiguous horizontal beds of a stratified portion of the mass. Vertical, or nearly vertical planes, however, along which the cohesion is much less than in the mass immediately on either side of them, may produce considerable modifications in the phenomena resulting from the action of the elevatory force. The existence of joints, for instance, or planes of cleavage, in the elevated mass, supposing the regularly jointed or slaty structure to prevail in it previous to its elevation, might affect in a most important degree the character of the phenomena." This author considers it impossible that a succession of parallel fissures could be formed in *thin* lamina subjected to such tension. "In any system of parallel fissures," he continues, "which are not remote from each other, the fissures could not have been formed in succession," though in an assumed case "of two systems of tension perpendicular to each other any number of parallel fissures may be formed simultaneously. It is evident that in whatever manner a system of parallel fissures may be produced after their formation, the only tension of the mass between them must be in a direction parallel to them. Consequently, should any other system be subsequently formed, it must necessarily be in a direction perpendicular to that of the first system. No two systems of parallel fissures not perpendicular to each other could be formed by causes similar to those of which we have been investigating the effects." And finally he states that "if the elevated mass be of great superficial extent, partial irregularities in its boundary will have no appreciable effect in the direction of the fissures; and though two remote fissures of the same system might, in such case, be inclined at any angle to each other, any two adjoining fissures would in general be approximately parallel."

DEVONSHIRE.—The fine Granitic mass of Dartmoor is considered by De la Beche "to have been protruded after, at least, the deposit of the upper part of the *grauwacke* series." He refers especially to the bent and contorted conditions of the carboniferous and other Slates around Dartmoor as showing the influence of the Granitic intrusion. There is, however, not any specific difference to be found between the Granite of Dartmoor and the Granitic masses of Cornwall. They are in both counties interpenetrated by Granitic veins and Elvan courses, and we have on the western side—at Peter Tavy—large masses of Greenstone, which may be traced on to Branstone and Dunderton, crossing the river Tamar at Greston Bridge. Long lines of Greenstone are also found skirting the Granite on its north-western edge from Great Cranaford to, and beyond, Okehampton. The southern half of Dartmoor is bounded by the Devonian rocks and the Killas or Clay-Slate of Cornwall, the northern boundary belonging to the Carboniferous series of Devon.

On the northern boundary of Dartmoor, we find the copper mines of Belstone and Furzdon (now Wheal Emily) in the Clay-Slate rocks, and a few mining explorations have been made farther south, at and near Bride-

stow. As we advance from Lidford onwards to Mary Tavy and to Tavistock, we find some important mines of tin, copper, and lead which is argentiferous, with many curious deposits of manganese between this point of Dartmoor and Launceston, and towards Tavistock, at Brent-Tor.

On the south, especially in the neighbourhood of Ashburton and Buckfastleigh, we find mines of tin and copper in the Clay-Slate; and passing westward by Brent and Ivy Bridge to Plympton, we have the well-known mine of Old Bottle Hill and several others.

The deposits of argentiferous lead ore in the Devonian rocks near Combe Martin are remarkable in many respects, and will duly receive attention. In the Devonian and the carboniferous rocks of North Devon peculiar Limestone veins occur. At a short distance from Bampton the author examined a lode of this description, which had suddenly changed to a vein of Bournonite (a sulphide of lead and antimony). This ore gave upon analysis—

Antimony	28
Lead	38
Copper	14
Iron	1
Sulphur	19
	100

and contained twenty-five ounces of silver to the ton of ore.

SOMERSETSHIRE.—The general form of the western portion of Mendip range may be thus described. Its highest part—which is, according to the Ordnance Survey, 999 feet above the level of the sea—includes Black Down. It presents a smooth uninterrupted surface for a considerable way down either declivity on the north and south; ravines then begin to appear, which in descending are enlarged into defiles or combs. On the southern side in particular the range is intersected by the deep defile of the Cheddar cliffs, which, in ascending to the north, ramifies into those sinuous dells and ravines that mark the southern face of the Mendips. On the northern side appear the two deep combs of Burrington and Dolborough; both enter the Mendips nearly at right angles with the vale of the Yeo.

The nucleus of the Mendip strata consists of the Old Red Sandstone, which occupies the highest part of the range in Black Down. In the more central part of Mendip the Old Red Sandstone is again seen in Nine Barrow Down, and about three miles to the north of Wells, extending in the direction of Chewton Mendip.

The Limestone on the north and south of this elevated part of Mendip forms a continuous body, which sweeps round the eastern extremity of the high Sandstone ridge. On the southern side of the highest part of Mendip the Limestone generally dips 20° at first to the south, 35° west, and subsequently to the south 20° west as far as Cheddar, a distance of three miles; but in the western direction, extending towards Crook's Peak, and the southern side of Blendon Hill, the dip is to the south 30° to 38°, west at an angle of 30° to 36°. The Sandstone strata on the northern side dip at angles gradually increasing from 7° to 30° or 40°.*

* Consult, for a more extended and detailed account of the geology of Mendip, Mr. Weaver's "Geological Observations of Part of Gloucestershire and Somersetshire" ("Geological Transactions," vol. i. Second Series).

Some years since (1816) a shaft was sunk at Stanton, above the village of Alcombe, in consequence of some indications of copper in the rock there, but the quantity of ore found was so small that the workings were soon given up. Mr. Horner found amongst the rubbish some pieces of green carbonate of copper with grey copper ore. Similar trials, with no better success, were made at Perry, near the northern extremity of the Quantock Hills. Mr. Horner found *there*, among the rubbish, specimens of malachite and of brownish-black sulphide of copper.

Nests of copper are occasionally found in the Limestone at Great Holwill, where Mr. Horner observed the green carbonate of copper enveloped by brown ochreous earth. At Doddington a large quantity was found some years ago. A loose friable quartzose Sandstone appeared to contain so much copper ore that a mine was sunk in it. In order to drain the works—which were situated upon the rise of the hill—a shaft was sunk for the purpose of driving a level, from north to south, up to the workings, expecting at the same time to cut across the veins of metal which might exist there, as they are generally supposed in this part of the country to run east and west. They had proceeded a very short way in driving this level when they came upon a black slaty Limestone, and immediately afterwards they found a nest of copper ore, consisting of green carbonate and yellow sulphide of copper. This mine was abandoned after a short trial, as the produce was not sufficient to bear the expense of an engine to drain off the water.*

In the preceding pages will be found some statements relative to the production of lead ore, zinc-blende, and iron ore on the Mendip Hills. These deposits are nearly always confined to the Limestone districts. In the Brendon Hills, chalybite, or *spathose iron* ore, has been for some years extensively worked. This form of iron ore—always associated near the surface with limonite (*brown hematite*)—extends over the Eisen Hill, and on to Exmoor. In this last district, extensive lodes are known; but except in ancient times but very few of them have been worked. At Winford, and extending towards Bristol, many hematite deposits have been found.

Sir Charles Lyell † remarks that "near Bristol, in Somersetshire, and in other counties bordering the Severn, the unconformable beds of the Lower New Red resting immediately upon the coal, consists of a conglomerate called 'Dolomitic,' because the pebbles of the older rocks are cemented together by a red or yellow base of Dolomite or Magnesian Limestone. This conglomerate, or breccia—for the imbedded fragments are sometimes angular—occurs in patches over the whole of the downs near Bristol, filling up the hollows and irregularities in the Mountain Limestone, and being principally composed, at every spot, of the débris of those rocks on which it immediately rests. At one point we find pieces of coal shale, in another of Mountain Limestone recognisable by its peculiar shells and zoophytes."

The metalliferous portions of this district are traversed by mineral veins in all directions, sometimes in such numbers as to constitute a kind of net-

* "Sketch of the Geology of the South-western Part of Somersetshire" By Leonard Horner, F.R.S. ("Transactions of the Geological Society," vol. iii. 1816.)

† "Manual of Geology," p. 305. Fourth edition.

work on a large scale. The veins observe no regular order in their dip, but are sometimes vertical, and often inclined one way or the other indifferently. Neither has it been observed that the metalliferous value of a lode in the Mendip Hills has any relation to either dip or direction. The lodes vary in width from one to six inches, but are sometimes enlarged, especially at points of intersection to the breadth of one, two, or even, in rare occasions, to three feet.

Few workings have gone down in the conglomerate to a depth of more than twenty or thirty fathoms. In all probability the veins do not penetrate into the subjacent Carboniferous Limestone or into the Old Red Sandstone.

Mining—but on a limited scale—has been carried on in the New Red Sandstone, and the Clay Marl formations, on the eastern borders of the Broadfield Down range. The district near Winford consists of the Carboniferous Limestone, which is succeeded by the New Red Sandstone, declining towards the vale. In this is found a clay ironstone—called in the district *Reddle*—which varies in thickness from five to six feet. To this bed pits placed at convenient distances are sunk, about eighteen yards in depth, and connected with each other by underground ways. The reddle thus obtained is used as a pigment. There are four or five small works at Winford, from which Brown Hematite is raised.

GLOUCESTERSHIRE.—The Limestone formations which surround the Coal Measures of the Forest of Dean have been from a very early period worked for iron ore, and considerable quantities of Brown Hematite are still obtained from this region. It should here be noted that this iron ore occurs rather as deposits—in the water-worn cavities of the Limestone—than in such fissures as are usually grouped under the term of "lodes" or "veins." Around Bristol from time to time lead ore has been discovered in the Limestones, but it has rarely proved to be of any importance. The geological formations north of Gloucester are rarely metalliferous. As we avoid the Coal Measures—which occupy largely the centre of England—there are no rocks of any mineral value which demand especial notice.

DERBYSHIRE AND ADJOINING COUNTIES.—The Romans worked the lead mines of this district, and probably the superficial deposits were searched by the earlier native inhabitants of this then wild region. The geology of Derbyshire corresponds very nearly with that of the northern counties. Farey* states that the lower part of Derbyshire is formed of 870 feet of Limestone, with three beds of igneous rock interspersed, whose aggregate thickness is 240 feet. Professor J. Phillips observes that these are surmounted by shale, with their alternations of Sandstone, Limestone, Ironstone, &c., to the extent of 500 feet, and the hills are crowned by bold ranges of Millstone Grit and its accompanying Sandstones, 360 feet in thickness."†

The uppermost regular strata in Derbyshire below the gravels is the Red Marl, which is bounded on the north by the great Derbyshire Fault, commencing near Colwick, in Nottinghamshire, and extending across the county, terminating in the coal-field of Newcastle-under-Lyne.

* Farey's "Derbyshire." † Phillips's "Manual of Geology."

CHERT, a silicious substance much used by the potters, is found in the Limestone in large detached masses, and also in thin strata.

GYPSUM, or *ALABASTER*, is a product of this district, forming thin beds in particular spots, and sometimes it is found accumulated in nodules of irregular and confused crystals. Chellaston Hill in particular would present a water-worn rock of gypsum were it not for the clay which covers it. In Nottingham and Staffordshire several gypsum beds appear.

This important mineral county, and the adjoining counties of Nottinghamshire, Leicestershire, and Warwickshire, have been frequently described. A large tract of this part of mid-England is remarkable for its Coal formation, which is beyond the province embraced by this volume; the minerals to which attention is directed being generally confined to the Limestone formations and to the igneous rocks, which are connected with the Limestones gathering around the Coal-basins, but rarely intruding upon them.

Farey devotes, in his work on Derbyshire, many pages to the consideration of the large deposits of gravel which are spread in patches, or in "hummocks" over nearly the whole of the county. He tells us, that he uses "the word 'gravel' to express every kind of alluvia with rounded stones," but in many instances in alluvial mixtures the stones are angular, almost like gun-flints in shape, as happens frequently with the *white chert* in alluvia on the Limestone strata, or, they are like the larger chippings of a stonemason's yard, and called *Ratchel*, *Rumel*, *Keale*, *Skerry*, or *Rubble*. . . . . If large, such are called *Boulders*; if rounded by attrition, *Self-stones* if possessing still the original shape and angles of the block. By the clearing of the waste lands, the boulders and 'self-stones' have been largely removed and broken up or converted into lime, or used in wall-fences and buildings, except that here and there a few such blocks are to be seen on commons or in particular fields which have not yet been cleared" (Farey was writing in 1811); "some because they will not answer the expense of such clearing, or *Ridding*, as it is more generally called."

He also gives a list of hills on the tops of which these detached stones are still to be found, and of narrow valleys which "have their bottoms still covered by large *Self-stones*." The *Slither*, or indestructible rubble of Limestone, which occurs generally in thin sharp-angled chippings of white and light grey and yellowish Limestones. These are lodged on the steep sides of valleys, and, curiously enough, are "in general the most barren spots that can be imagined, not a blade of grass, a weed, or even a lichen having got possession of them, nor do they exhibit the least signs of decomposition or mouldering. In general this indestructible rubble lays on so steep an ascent that it slips from beneath the feet of an animal which attempts to cross it—whence the name *Slither*, or sliding gravel."

The *Red Marl* occupies most of the southern end of the county, and spreads over Nottinghamshire, Leicestershire, Warwickshire, and Staffordshire, being bounded on the north by the *Great Derbyshire Fault*, which commences at Colwick in Nottinghamshire, and extends across to Cheshire, where this red marl produces the highly valuable beds of rock salt and brine

springs, with gypsum, which also occurs and is worked largely in Nottinghamshire.

The Sienites—or Granites of Playfair—are not materially connected with the metalliferous conditions of this large district of Central England. These are more especially developed at Mount Sorrel, in Leicestershire, at Bardon Hill, and the Grooby Quarry, near Ashby-de-la-Zouch.

SLATE.—The Slate rocks, although of great economic value, have no direct relation with the mineral deposits of this district.

MILLSTONE GRIT is the most important stratum of Derbyshire. By its thickness, its hardness, and indestructible properties it gives rise to the most striking scenery of the county. In several places this rock is 120 yards thick. It is composed of a coarse-grained white, yellow, or reddish freestone, easily worked, and of vast durability.

The Peak Millstones, which are known all over England, were for a long period manufactured at Belper and to the north of that place. They are now manufactured in Derbyshire, Yorkshire, and Cheshire.

Some of the series, which are remarkable by having spherical stones of a light red colour, form the best *Fire-stones* known, and are much used for lining the hearths of iron blast furnaces and other smelting works where intense heat is required. The upper beds are used for paving-stones and flags, and they split so thin that they are employed for covering buildings.

This rock is found scattered over a wide area in Derbyshire and extending into the other adjoining counties. The gaps, however, show very plainly that it has been subjected to an immense central denudation. This is, however, of great benefit, as it has laid bare the great mineral Limestone tract of Derbyshire and Staffordshire.

THE GREAT or LIMESTONE SHALE.—This has been proved by the shafts in the lead mines to have a thickness of from 150 to 170 yards. This contains the *Shale Limestone*, said to be the bituminous marl Slate of Werner, which produces the well-known polishing powder, *Rotten-stone.* Ironstone is found in considerable beds in this *Shale.*

MOUNTAIN LIMESTONE.—The Geological Survey has given a section of this formation between Monsal Dale and Buxton:—

	Feet.
1. Thinly-bedded Limestone, somewhat earthy, with layers and nodules of chert, and thin shale partings in the lower beds	250
2. Thickly-bedded Limestone	50
3. Thinly-bedded Limestone and chert	90
4. Toadstone, perhaps in places as much as	100
5. Massive white Limestone, Miller's Dale rock, with perhaps a bed of Toadstone in the middle, at least	320
6. Toadstone, about	20
7. Very thickly-bedded white Limestone, Chee Tor rock	500 to 600
8. Limestones, more or less concretionary, with shale partings	150
9. Limestones, some thickly and some thinly bedded: of these there is seen about	100
Total thickness shown without reaching the bottom	1,580

The cutting at the east end of the Monsal Dale tunnel, where the first bed rises, in a series of easy rolls, from beneath the Yoredale shales and earthy Limestones, gives the following section:—

SECTION SHOWING THE JUNCTION OF THE YOREDALE BEDS AND MOUNTAIN LIMESTONE AT THE EAST END OF MONSAL DALE TUNNEL.

		Ft.	in.
Yoredale Rocks. Lowest Group.	Black shale.		
	Earthy Limestone	1	6
	Black shale	6	0
	Limestone	2	0
	Black shale	0	5
	Calcareous black shale	0	7
	Black shale	0	10
	Earthy Limestone	0	9
	Black shale	11	0
	Limestone	1	0
	Black shale	1	8
	Limestone	2	6
	Black shale	0	3
	Limestone	2	5
	Black shale	1	9
	Earthy Limestone	0	9
	Black shale	0	10
	Earthy Limestone	1	0
	Black shale	0	11
Mountain Limestone.	Thinly-bedded Limestone with chert, No.		

Crossing the river we find the same cherty beds as on the east of the tunnel, and below them like thinly-bedded Limestones with shale partings. There are two very small faults, and near one of them the rock is curiously veined with calc-spar; a little farther on, a lode crosses the line, its fissure is about twelve feet wide, filled in with calc-spar, among which is scattered a little galena; the crystals are mostly in prisms ranged at right angles to the walls, but in the middle there were some concretionary nodules.

From beneath these cherty beds rise a more thickly-bedded Limestone, No. 2, beneath which there are again about ninety feet of Limestones and chert, No. 3.

At the west end of Cressbrook Tunnel a thickly-bedded white Limestone, No. 5, comes out from beneath No. 3, and runs on through Litton Tunnel, to the west of which the beds dip down, and the cuttings are in beds belonging to No. 3, which are here fossil bearing, and have among them thin lenticular partings of shale and red clay.

No. 5, being carried down by the dip just mentioned below the level of the railway, forms a range of fine cliffs along the lower part of Miller's Dale, and may be traced along the steeply-scarped sides of the valley, while beds belonging to No. 3 are shown in the cuttings above, till we come to Litton Mill. Opposite this mill, however, instead of Nos. 5 and 3 being in contact, as was the case at Cressbrook and Litton tunnels, they are parted by a thick mass of *Toadstone.*

The Carboniferous Limestones of Derbyshire yield a variety of beautiful marbles, which are used for numerous ornamental purposes. In various parts a *black marble* is found in laminæ, the colour being derived from iron and petroleum.

The Mountain Limestone stratum produces the principal mineral veins, which contain galena (the sulphide of lead, which generally in Derbyshire contains but little silver), the sulphide of zinc, blende or "Black Jack" of the miners, and a native oxide of zinc. Ochres in great variety are found, with fluor-spars of varied colours and often of great beauty, sulphate of

barytes (*Cawke*), and carbonate of pyrites (sulphide of iron, *mundic*), and at Ecton large quantities of copper were found, and some in the adjoining mines.

Yellow Limestone, or, as it is more frequently called, Magnesian Limestone, comes next in order. In the "Memoirs of the Geological Survey of England and Wales" this formation is thus described:—

"This is a mass of Limestone of very great but unknown thickness. Very thin partings of shale or clay are found in it here and there, and two or more beds of contemporaneous igneous rock, called Toadstone.

"In the upper portion the Limestones are thinly bedded and somewhat earthy, and contain layers and nodules of chert. Below the cherty group comes a great thickness of exceedingly massive pure Limestones, at times semi-crystalline, of white or pale grey colour; and underneath these there is a mixture of thickly and thinly bedded Limestones."

The Magnesian Limestones cover an immense series of Coal Measures, which distinguishingly mark the central portion of England. With these, the most valuable of our mineral productions, we have not at present to deal.*

The interest which attaches itself to the geology of North Derbyshire is such, that a much larger space would have been devoted to its consideration but for the pressure of other matters which are directly connected with the mineral deposits, our especial subject.†

Farey remarks: "It is now supposed by many practical miners—and so they construe their titles to the veins—that every principal vein extends through the whole series of Limestone rocks, as from the top of the first lime to the bottom of the fourth, but not without interruption, since the three *Toadstone* rocks are very rarely broken through, I believe, so as to connect the veins above and below them, except where *faults* have since happened to follow the ranges of the veins."‡

THE TOADSTONE, which seems to be a truly interbedded rock, varies from a soft crumbly ash to a hard closely-grained Greenstone. Our imperfect knowledge enables us only to say that the most usual form of Toadstone is an ashy rock. The number of the Toadstone beds is still uncertain. The late Mr. W. Hopkins, the well-known mathematician, endeavoured with great ingenuity to explain all the facts bearing on the matter which he could collect, on the hypothesis of there being only one Toadstone. He does not seem to have been aware that two, and perhaps three, beds of Toadstone have been sunk through in the same shaft; but, besides this, he was obliged to call to his aid faults many of which have certainly no existence. White Watson, in his "Delineation of the Strata of Derbyshire" (1811), gives three beds of Toadstone, and this was also Farey's view.

* The reader interested in the Coal Measures of the kingdom, and the argillaceous iron ores which they contain, should consult "The Coal and Iron Industries of the United Kingdom," by Richard Meade. Crosby Lockwood & Co. 1882.

† See "The Geology of the Carboniferous Limestone, Yoredale Rocks, and Millstone Grit of North Derbyshire," &c. By A. H. Green (Le Neve Foster) and T. R. Dakyns. ("Memoirs of the Geological Survey." 1869.)

‡ Werner, it is stated, understood that "the *veins in Derbyshire* generally descend through the *Toadstone*;" and Dr. James Millar, of Edinburgh, adopted the same view. Mr. Westgarth Forster, in his "Treatise on a Section of the Strata," curiously confounds mineral veins and *faults*. It is probable that one set of faults becomes, being filled in with mineral matter, mineral veins; but many faults are never so filled.

"There seems reason to believe that in places there are three beds, but that they are liable to thin away, as indeed is only likely; but we cannot surely say, till the Limestone country has been more thoroughly examined, how many Toadstones there are, and whether any or all of them spread uniformly over the whole district; for instance, it would be very rash to assume that the highest Toadstone of Matlock and the highest Toadstone of the neighbourhood of Buxton belong to one and the same bed."

The Toadstone of Derbyshire plays so important a part in the phenomena of the lead lodes of the district that its conditions should be thoroughly understood. Professor J. Phillips thus describes it: "Only one case of interposed pyrogenous rock occurs in the Limestone tract of England to the north of Derbyshire, but this is one of the most extensive examples known in geology, and has given rise to several descriptions.

"The Toadstone of Derbyshire, whether it be a single or a triple mass, may be considered as one great eruption of melted rock interpolated in the Limestone series; the *Whin-sill*, as it is called in Yorkshire, Durham, and Northumberland, is another. They do not correspond in position among the strata; the Toadstone lies among lower beds than the whin-sill. They agree in some respects, both being to a certain extent stratiform, irregular in thickness, variously traversed by faults and veins."

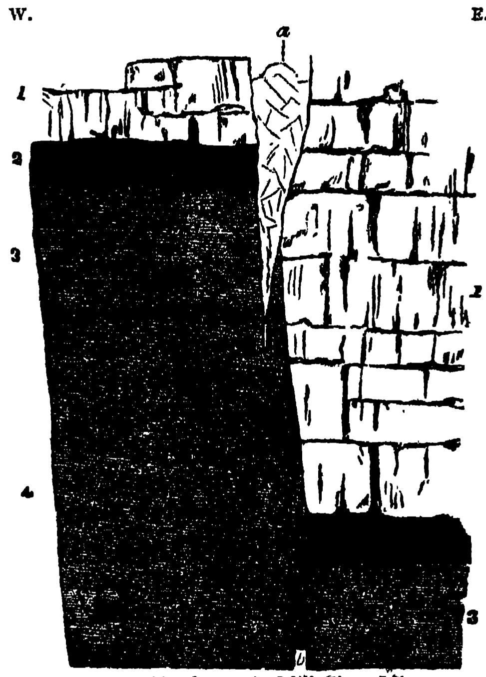


Fig. 27.—Toadstone in Mill Close Mine.

Scale, 5 feet to 1 inch.—1. Limestone. 2. Black bituminous unstratified clay. 3. Soft, crumbly, greenish Toadstone. 4. Irregular masses of amygdaloidal ashy Toadstone, embedded in softer but similar rock. *a.* "Leader" of Calc-spar. *b.* Belt of Toadstone crushed against the fault.

It will be apparent from the above quotation that conditions of the *Elvan courses* of Cornwall, the *Toadstones* of Derbyshire, and the *Whin-sills* of the North of England are in many respects similar to each other. They are intrusive rocks—they preserve all the special characteristics of melted rocks—and thus the influences on the strata amongst which those igneous masses are interposed is in each district of a similar character. We introduce here a striking example of the Toadstone in Mill Close mine (Fig. 27).

In small veins we often find the *Toadstone* entire between the veins, forming what Farey calls a *sole-stone* to the vein above it and a *lid-stone* to the vein below it, of the full width of the vein in each case; but from the larger veins a crack or rent generally extends some distance into the *Toadstone*, growing narrower, and often branching into small cracks, *strins*, or strings as it proceeds, and in the same manner the veins often

strike into the shale which covers the first Limestone. Those are said by the miners to be very *powerful veins* which break through the Toadstone. There is evidently a considerable amount of confusion in this view. If attention is confined to two rocks, one much softer than the other, one very liable, by several agencies, to be broken into fissures, while the other is very tough, this will be apparent, and the difficulty will be removed. After the intrusion of the Toadstone, possibly at the very period of its intrusion, the Limestone has been cracked, all the cracks terminating at the tougher rock, consequently, when those fissures are filled in with metalliferous matter, this deposition ceases at the *Toadstone*. In some cases the fissure in the Limestone may run *close up* to the Toadstone, and then when the crystalline force, generated in the crystallization of the sulphide of lead, takes place in the true vein, it may produce fine cracks in the Toadstone. These cracks admit the fluid holding galena in solution, and this by crystallising may enlarge those cracks in the Toadstone.

The *Toadstones* are liable to decomposition, and then to form a tenacious clay, beds of which are known as *wayboards*. Even thick beds of this clay divide the larger veins. May it not be that the division took place previous to the Toadstones' decomposition or disintegration, whichever it may be? It is stated that these *wayboards* often hold up and completely divide the water of springs in different parts of the Limestone rocks.

Farey very nearly approached the truth when he wrote: "The Limestone strata were subject to a great contraction or shrinking since their formation and consolidation, which did not extend to the Toadstones, to the principal *wayboards*, or to the shale above; yet the mechanical force with which the sides or *skirts* of the veins drew apart rent or tore the *Toadstones* and the shale for certain distances, where the veins abut against them. And since the *Toadstones* and the *wayboards* effect in general a complete separation, even to water, in the different parts of the veins, besides the shale and a vast thickness of upper measures having covered the whole, it seems difficult to conceive any other origin to the spar and the metallic ores which line those cracks or veins than infiltration of some sort from the adjoining rock—a supposition which receives confirmation from the fact so well known to miners of certain beds of Limestone in some of the rocks producing more *ore* in the veins *between them* than is found in other beds in the same rock; when such are called *bearing measures*, or feeding-ground, by miners. The two sides of a large *rider*, or near or parallel veins, are *seldom, if ever, rich together*." This may be true of the lead lodes of Derbyshire, but numerous instances are known to the author, where the resemblance between the two sides of a lode prove that they were produced under precisely similar conditions, and consequently that the depositions are strictly similar. In continuing his description of mineral veins, Farey gives several remarkable instances of curious variations which are well worthy of attention. "Next to the walls or *skirts* of the veins, which are of unequal distance apart in the same vein, in many instances a lining of *vein stuff*, as crystals of calcareous spar, of fluor-spar, and sulphate of barytes (*Cawke*), is applied; which vein stuff in some narrow places or *humps* in the vein-skirts have met, and there the vein is said to be *twitched* or *nipt-up*, and little or no ore is there found. Upon the linings of spar or first formations of vein stuff a

certain thickness of lead ore is deposited—generally the sulphide of lead (galena or blue ore in cubes)—which are called either *steel-grained* or *leaf ore*, from having a fracture something like a thorn leaf, and it often happens that the original width of the vein and the thickness of deposited spar was such that these crystals of ore meet, and are closely wedged together, forming what is called one *rib of ore*, with spar on each side of it in the vein. In wider veins it has happened sometimes that a second deposit of spar took place upon the lead ore, and continued increasing until the sides met and were close wedged, and such parts have two ribs of ore. . . . . .

"In many instances, instead of regular ribs of ore being found, the deposits of ore and of spars of different kinds seem to have gone on together, and the ore is found dispersed in different-sized cubes, more or less perfect, throughout great part of the vein stuff; and indeed it seldom happens that the spar is entirely free from small cubes of lead ore even where ribs of ore are met with."

SLICKENSIDES, or, as in Derbyshire called, "*cracking-whole*," are divisions going vertically through the strata, especially the vein stuff. The surfaces are always polished, sometimes to a state of mirror lustre. These surfaces appear to be produced by the immense attrition produced on two faces by rubbing them together. Sometimes the slickenside is ribbed or slightly fluted horizontally; the sides are always in very close contact, and the surfaces appear to be in a state of extreme tension. It sometimes happens where one side is removed that fragments called in Derbyshire *slapits* or *spels* fly off with loud explosions, and continue to do so for some days. The Gang mine, near Cromford, was remarkable for this. In this mine the miner availed himself of a curious property attending *slickensides*. He drew *laces*, *stoops*, or *nicks*, as he called incisions, at about six inches apart and four inches deep, with the point of his pick, from top to bottom of his face work, which he then left for several hours; and on his return he would find all the vein stuff *furrowed*, *spelled*, or *slappited* off, and laying on the sole ready got to his hands. The Slickensides in the Eyam copper mine would, according to Mr. Whitehurst, explode upon slightly scratching. Farey gives the strata in which the most productive lead mines occurred in Derbyshire, in 1811:—

In shale and shale Limestone	
In shale Limestone . .	
In shale and first Limestone	56
In first Limestone . .	104
In first and second ditto .	10
In second ditto . .	16
In second and third ditto	4
In third Limestone . .	33
In third and fourth ditto .	13
In Toadstone	3
In Limestone rock	32
	279

In 1881 the number of lead mines worked in Derbyshire was 240.*

WHIN-SILL.—Many memoirs have been published on the peculiarities of the various basaltic rocks of Great Britain. Yet the question whether the whin-sill is intrusive or contemporaneous has scarcely been satisfactorily settled. It is often spoken of as "interstratified," and as occurring in "overlying masses." Mr. Trevelyan, in 1823,† published a paper on the northern

* For list, see "Mineral Statistics of the United Kingdom for 1881."
† "Memoirs of the Wernerian Society," vol. iv. p. 253.

coast of Northumberland. Professor Sedgwick* printed two papers on the Trap rocks of Durham. He thought there was abundant evidence of intrusion, the beds below being frequently broken and partially closed within the whin, whilst the beds above have suffered that change which is implied by the uncertain term of metamorphism. Mr. W. Hutton† wrote in considerable detail of the whin-sill of Northumberland. He regarded it as strictly contemporaneous, and where two or three distinct beds are known in one district he supposed that there had been successive eruptions upon the ocean floor.

Professor Phillips admits some eruptive force, but only sufficient to allow of the whin reaching the sea bottom.‡ At a later period he stated that he had proved the intrusive nature of this rock. The following remarks by the officers of the Geological Survey who surveyed the country are much to the point § :—

"The whin-sill is older than most of the faults of the district in which it occurs, because these throw trap and sedimentary beds alike. We have no clear case of the whin being unaffected by (or later than) any of the faults. The whin is also clearly older than the mineral lodes of the district. But what the age of faults and lodes may be we do not know. Some of the faults are probably pre-Permian; at least the Magnesian Limestone appears to be unaffected by certain faults which are proved in coal-workings beneath. Others, and these generally the large east-and-west faults, are clearly post-Permian. But we cannot generalise as to the age of the faults in this district merely by their direction; and even if we could, the known instances of faults in the whin-sill are not sufficiently numerous to allow us to apply the test with safety.

"If the Permians can be shown to have been deposited upon the *denuded edges of the trap*, the proof is complete. But it is only very rarely that such proof can be given. Generally, the evidence is of this nature:—Carboniferous rocks, in which intrusive sheets of trap now occur, have been disturbed and denuded, and their edges covered up by unconformable Permians. This, however, is not sufficient proof; or rather it is no proof at all; for the trap may have been intruded into the carboniferous rocks long after the deposition of the Permians. There is evidently a tendency for these sheets of trap to keep along the lines of bedding; otherwise there would never be any doubt as to their character. If the intruding trap began to force its way laterally first through the carboniferous rocks, it would probably, if possible, stay there."

Farey, in his "Derbyshire," gives "A List of Hummocks of Mineral Limestones and Toadstones," which distinctly marks the situation of these two rocks, and beyond this he gives a list of the more important mines which have been worked for lead, zinc, manganese, copper, iron, &c.

Messrs. Green, Foster, and Dakyns, of the Geological Survey, regard the Toadstone as an amygdaloidal rock, which they think is well shown where it has decomposed into a soft friable clay. For by washing this, or merely rubbing it between the hands, one may pick out the small rounded or almond-shaped kernels of carbonate of lime which once filled the cavities in the

* "Cambridge Transactions," vol. ii. pp. 21, 129.
† "Transactions of the Natural History Society of Northumberland," vol. ii. 1832.
‡ "Geology of Yorkshire," part ii. p. 285.
§ "On the Intrusive Character of the Whin-Sill of Northumberland." By W. Topley, F.G.S., and G. A. Lebour, F.G.S. ("Quarterly Journal of the Geological Society," vol. xxxiii.)

vesicular rock. These pieces of carbonate of lime are coated with a green mineral, and the rock thus acquires a speckled look, showing green spots on a yellowish-brown ground. The same authorities say: "The facts that have incidentally come under our notice respecting the condition of these formations are neither numerous nor well connected, but they tend to overthrow the formal subdivision of the old geologists, Farey, Whitehurst, Watson, and others." According to these observers, there are three beds of Toadstone, spreading without break over the whole district, and dividing the Limestone into four portions, called the first, second, third, and fourth Limestones. There would be nothing strange in beds of lava or volcanic ash being very irregular in their occurrence, and the sections show that, perhaps with one exception, Toadstones are found at different spots on very different horizons, and are of limited horizontal range. Beside the three regular beds mentioned they admitted the existence of "chance" Toadstones, that is, Toadstones of local and irregular occurrence; but it seems likely that all the Toadstones partake more or less of this character. These authors also speak of the several Limestones as if they each bore some distinctive stamp, which enabled the observer to recognise them by character, independently of relative position. With the exception of the upper *cherty beds*, our experience does not tend to confirm this view. Indeed, the attempt to identify beds far apart by mineral character alone, has been a fruitful source of error, not only here, but also among the Gritstones and other parts of the Carboniferous rocks; for instance, the Kinder Scout Grit of the Peak and the Third Grit of Chatsworth were long, and very naturally, looked upon as belonging to the same bed, because each was the lowest coarse grit in its own neighbourhood. The fact that mistakes of much significance have been made shows that for such details as these, nothing but careful mapping of the *whole* of the country can be a safe guide, and proves the danger of the old-fashioned method of taking a section here and a section there, and guessing at the probable identities of the beds.

The following section of the Toadstone is given by the same authors:—

Thinly-bedded Limestones with chert; false bedding in the lower part.

Toadstone.
- (1.) Soft, crumbly, yellow clay.
- (2.) Dark olive green, mottled, coarse ashy *Toadstone*, amygdaloidal in parts; with large rounded lumps, finely grained, hard and yellow, also amygdaloidal at times.
- (3.) *Toadstone*, dark olive green, and more solid.
- (4.) Ditto, shaly, with concretions.
- (5.) Hard, dark grey, finely-grained Toadstone.
- (6.) *Toadstone*, soft, concretionary, and vesicular.

Thinly-bedded Limestone full of corals } a few feet thick.
Ditto ditto with shale bands }
Massive white Limestone.

"We believe," they say, "that each of the divisions of the Toadstone is a true bed, with a gentle dip to the east; and in this case the whole will be about 100 feet thick. All the beds were very ashy, but some had the look of a truly melted rock. There was no sign of alteration in the underlying Limestones at their junction with the Toadstone.

"It must be allowed that so rapid a thinning out of the Toadstone as is required by the above explanation is somewhat startling. After a careful ...on of the ground, however, we could come to no other conclusion,

and as the rock seems more of an ash than a true lava, there is after all nothing so very strange in its coming sharply to an end."*

The accompanying section of the mineral Limestone and Toadstone series will explain their relative positions and their average thicknesses nearly, the Toadstone strata being liable to vary in their thicknesses. The first Limestone bassets regularly from under the great shale, all the way from Ranter mine, near Wirksworth, to near Quarter House, north-north-west of Great Flucton, north in an irregular line. The boundary is principally limited by a vast fault—the Great Limestone fault. From Wirksworth south-westward to Hopton a part of the same great fault separates the third Limestone from the great shale, &c., south of it.

"Each of the three Limestone rocks," says Farey, "has its regular but crooked range and basset edge from south to north. The first rock from Wirksworth to North Hucklow and to Quarter House; the second lime from the Great Limestone fault in Middleton Wood on the north of Middleton by Wirksworth to the same fault, again on the south side of the Windmill Houses near Great Hucklow; and the third Limestone from the same fault between Wirksworth and Hopton, south, to the same fault, against which it abuts from a point south of Windmill Houses to Castleton Town (Fig. 28).

Section across a Part of the Lode at Great Hucklow.

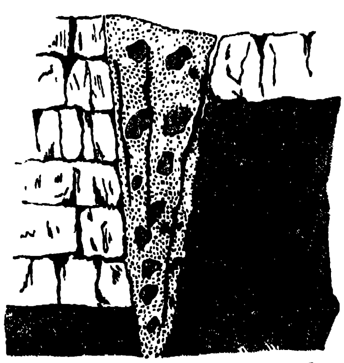


Fig. 28.—Section of Limestone and Toadstone.

Scale, 80 feet to 1 inch.—1. Limestone. 2. Toadstone. 3. Lode filled with "kebble," and "horses" of Limestone and Toadstone; black lines, strings of galena.

"In like manner the three Toadstone strata each abut against the same fault at the south and north ends of their respective ranges. The first Toadstone, about one-third of a mile north-west of Middleton by Wirksworth, and again about three-quarters of a mile north-north-east of Litton, near Tideswell; the second Toadstone about a quarter of a mile west of Cromford and again one-third of a mile west of Windmill Houses; and the third Toadstone from the same fault, about five-eighths of a mile west of Cromford, and meeting it again near the entrance of Cave Dale in Castleton Town. The phenomena of isolated patches of these strata detached from the range or basset of them arise from two distinct causes, they being in one case the remaining patches of strata which have been stripped off or denuded around them, and in the other the superficial strata have been excavated or denuded locally, so as to show patches of the under strata surrounded by these upper strata. The first of them are peculiar to the tracts proper to the lower strata (when not occasioned by a sudden lift of the strata), and are called *Hummocks*; the other, when not occasioned by a sudden sink of the strata, are found only in the tracts proper to the upper strata to those detached" (*Farey*).

Whenever a vein occurs underneath a Toadstone bed it is seldom of the

* W. Topley and G. A. Lebour.

same width, or of the same nature *exactly* as that above it, nor are they directly under each other, although generally they follow about the same range. Veins with such deviations are said to be *squinted* or *leapt aside*,* and this deviation is in some instances so considerable, that lawsuits have arisen to determine whether they are the same veins or not. The occurrence of lead ore in Toadstone is rare. There has been an opinion that this mineral is found in Limestone only, but this idea has been somewhat too hastily adopted. In the neighbourhood of Matlock, at the Side mine, under the High Tor, and at the Seven Rakes mine, on the right side of the river, not far from the bridge, this ore has been severally worked. The vein in the Seven Rakes mine was formerly worked to the depth of about thirty fathoms in the first Limestone, when, on coming to the Toadstone, the work was abandoned, as it was supposed that the vein was cut off by that bed. Some years afterwards a level was driven into the hills from near the river to carry off the water, and the vein was worked in the second Limestone, underneath the Toadstone, which was left untouched. The vein was again abandoned when the workings were carried to a depth at which they could no longer be kept clear from water. But in 1819 five working miners took a set of the ground, in order to work the vein in the intermediate Toadstone, which had been left, and the undertaking proved profitable.

The owner of the Side mine stated that the veins in all cases with which he is acquainted are continued through the Toadstone, and frequently change their degree of inclination in passing through that rock, and that sometimes after such a change in inclination the vein again returns at an abrupt angle, like a V placed horizontally. Frequently the lodes do not bear well in this Toadstone.†

The following names have been applied to the *Toadstones* in *Derbyshire*: amygdaloid, black clay, basalts, boulder stones, brown stone, cat dirt, channel, chirt, clay, dunstone, ferrilite, fiery dragon, freestone, jewstone, ragstone, trap, tuftstone, whinstone, secondary traps, and others.

Dunstone (a term used by Mr. W. Hopkins, but not generally adopted).—There exists in the neighbourhood of Matlock, on Middleton Moor, by Wirksworth, to the east of Newhaven, and in some other places, a formation known by this name. It is different from Limestone, inasmuch as it contains a very small portion of calcareous matter; and that, as a geological formation, it is not identical with the *Toadstone* is rendered conclusive by the circumstance of its being in many places as distinctly stratified as the Limestone itself. Mr. Hopkins regards it, "therefore, as a distinct formation, any one continuous bed of which must have had its particular epoch of deposition. If the epoch of the formation of the first Toadstone occurred after that of the Dunstone bed, this latter will lie entirely in the second Limestone, so that though of two continuous beds of Dunstone (supposing them to have had different epochs of deposition) one might possibly be in the first and the other in the second Limestone, neither of them could lie partly in one, partly in the other.

* Werner was of opinion that the Toadstone occasioned the *squinting* of the veins or their being "thrown to a side" by its very unequal thickness and hardness. See "New Theory of Veins," p. 129.

† See "Notice accompanying Specimens of Lead Ore found in Toadstone from near Matlock, Derbyshire." By Charles Stokes, Esq., F.R.S. ("Transactions of the Geological Society," Second Series, vol. i. p. 163.)

"The stratification of the Dunstone* cannot always be easily recognised, but the most obvious instances may be found at the upper end of Gratton Dale and on Middleton Moor, by Wirksworth, in both which places it gives to the scenery a peculiar wild and striking aspect. I have sometimes remarked the Toadstone as being *laminated*, but it never presents the remotest trace of *stratification*." †

YORKSHIRE.—The principal ores produced by the Mountain Limestone of Yorkshire are sulphide of lead (galena), sulphide of copper (yellow and grey copper ore), sulphide of iron (pyrites, mundic), sulphide, carbonate, and oxide of zinc (blende, black jack, &c.). Iron ores are also found. These ores, excepting iron, are all connected with spar veins, fissures, or rock dykes. No instance is known of any one vein being continuous from the Slates of Cumberland into the Mountain Limestone tract. No case, remarks Professor J. Phillips, is known of any vein being worked in the Old Red Sandstone; no vein has been worked in Yorkshire above the Brinham Millstone Grit, though lead ore has occurred in veins in coal seams above that rock, and strings and nests of lead ore and copper ore have been met with in Magnesian Limestone at Nosterfield, Farnley, Newton Kyme, and Warmsworth. Calamine, and white oxide of zinc occur, chiefly in the lower Scar Limestone in Bolland, near Whitewell, and at Mallam. South of Wensleydale it is in the lower Scar Limestone principally that the lead mines of Greenhow, Nidderdale, Grassington, Kettlewell, &c., have been worked, but to the north of Wensleydale the Scar Limestone becomes the most productive. In the mining districts of Greenhow, Grassington, and Kettlewell veins yield ore both in the Limestone and Millstone Grit series. Veins have been found more or less productive in the Millstone Grit series south of Lotherdale, and in the line of the Auldgang (Old Gang) vein in Swaledale and Arkendale. Mines are worked in the Whin-sill at several points north of Maize Beck.‡

Mr. Thomas Sopwith observes of Yorkshire: "Most veins in the mining districts preserve a tolerably direct course for a considerable distance, some, indeed, for several miles." (We are disposed to think this requires further examination). "They are commonly designated *veins*, *cross veins*, and *quarter-point veins*. The former are sometimes called *right veins*, their course being east and west, or a little north of east and south of west. Those which have a bearing nearly north and south are called *cross veins*. The few veins which have a bearing between these are called *quarter-point veins*."

The relation of "*hade and throw*" must now be noticed. A general law has been accepted by miners and colliers to which in secondary strata few exceptions have been found. It may be thus expressed: The "slip" or plane of dislocation hades, dips, underlays, or is inclined to the vertical so as to pass under the depressed portion of the strata which are displaced.

Thus A is the *downcast* or depressed set of strata, and B the *upcast* (it

* A manuscript note—which is recognised as the handwriting of Sir Henry de la Beche—says, "It is, I find, a *Magnesian Limestone*."

† "On the Stratification of the Limestone District of Derbyshire." By W. Hopkins, M.A. 1835. Printed for private circulation.

‡ "Illustrations of the Geology of Yorkshire." By John Phillips, F.A.S., F.G.S. 2nd edition. 1835.

must not be supposed that any upward movement was necessary), V V the plane of dislocation, inclined from V to V the vertical so as to dip under the downcast side (Fig. 29).

In mining language the beds are highest on the *ledger* (lower) side of the vein, and lowest on the *langor* (upper) side.

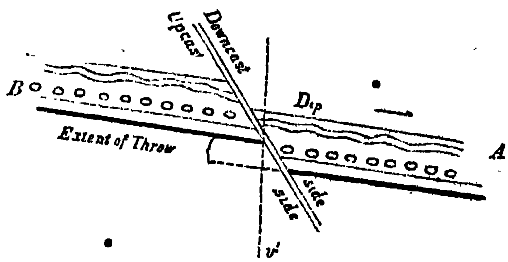


Fig. 29.

The width of the fissures varies with the character of the rock, being open in Limestone, contracted in Gritstone, but much reduced in plate.

The Great Limestone of Alston Moor can be traced to Limedale in Yorkshire, and to Wensleydale, where it is commonly called the "Twelve-fathom Limestone."

The section of the Mountain Limestone and Millstone Grit in Wensleydale is thus given by Professor Phillips:—

MILLSTONE GRIT SERIES.	Coarse and fine Sandstone, shales, and coal . . . . . . Coarse, fine, and slaty Sandstones, shales, cherty beds, and coal . Millstone grit of Ingleborough, shales, cherts, and coal . . .	700 feet.
UPPER LIMESTONE BELT.	Thin Limestone, Sandstone, and shale . . . . Main or 12-fathoms Limestone, shales, Sandstones, and coal underset Limestone	200 ,,
FLAGSTONE SERIES.	Alternations of flagstones, of various quality, in great abundance, with shales, coal, hard gritstones, and three or four strata of Limestone from 6 to 30 feet thick. The black marble of Dent is nearly at the bottom of this group	500 ,,
SCAR LIMESTONES.	Limestones of great thickness, with partings principally of shale .	500

The "twelve-fathoms Limestone" is comprehended in the central part of the upper Limestone belt. From this it is evident that the distance from the bottom of the Scar Limestone does not differ materially from that intervening between the bottom of the Melmerby Scar Limestone and the Great Limestone as developed in Cumberland. This thickness also corresponds with that of the mineral Limestones and Toadstones of Derbyshire.

The following remarks may be viewed as mainly those of Professor Phillips. They are abstracted from his admirable treatise on "The Geology of Yorkshire," more especially the second part, which treats of the *Mountain Limestone district.* Although not disposed to receive all his positions as established, yet they are deserving of the closest attention, as the conclusions of a most accurate observer and of a thoughtful mind.

From the facts above mentioned it follows that the dependence of particular metallic products on particular series of rocks is principally a local phenomenon without general application; but, on more minute analysis of the phenomenon, it is found that in a given district certain beds generally *are* and others generally *are not* productive of metallic treasures. A particular vein, for example, in Swaledale traverses Millstone Grits, plates, and cherts; Main Limestone, grits and plates; undersill Limestone, grits, plates, &c.; and it is a matter of experience that among these beds only the conso-

lidated silicious and calcareous beds are productive; in the argillaceous plates the veins are mostly "dead."

If in consequence of the displacement of beds along the vein solid rocks on one cheek are opposed to argillaceous beds, the veins (unless *very strong*) will probably be unproductive.

The Limestone district of the north of England produces but little copper. Conishead Priory, Alston Moor, and Middleton Tyas are exceptions. It is remarkable that there is a line of mineral deposits passing north by west, parallel to the eastern range of the carboniferous deposits, principally yielding copper ore in Magnesian Limestone at Newton Kyme and Farnley, and in Main Limestone at Middleton Tyas.

Swaledale, in Yorkshire, is distinguished especially by its Mountain Limestone formation. Millstone Grit caps most of the highest hills; the *sixth-set Limestone*, with a considerable thickness of alternate bands of grit and plate under it, forming the lowest observable Limestone beds in the dale.

The characteristic deposits are of the following thickness:—

Limestone	*calcareous*	45	fathoms.
Chert	*silicio-calcareous*	15	,,
Grit	*silicio*	75	,,
Plate	*argillaceous*	40	,,
		175=1050 feet.	

The *chert* beds are distinguished by the names of the "Crow Chert," the "Main Chert," and the "Underset Chert."

The *grit* is a highly silicious and often micaceous deposit. When worked freely it is called Freestone. It consists of three parts of silicious sand, with one of mica and oxide of iron. The chert beds are uncertain in the production of the ores of lead to the Limestone beds; but the grits of Swaledale are usually unproductive.

The *plate*, or *shale*, is an argillaceous deposit of a more or less fissile structure often containing fossils.

The *grits* and *plates* may be regarded as the unproductive or non-metalliferous deposits.

The *Limestones* and *cherts* are the lead-ore-producing beds. The *main chert* and Limestone are by far the most valuable lead-ore-producing beds throughout Swaledale.

CUMBERLAND AND WESTMORELAND.—In the north of England the Mountain or Carboniferous Limestone forms a very distinct and easily recognised series of rock. Geologists have given a total thickness of 2,800 feet to it in the northern counties, and it consists of a series of alternating strata of Limestone, Sandstone, Shale, intersected by Trap rock. In the mining district of Alston Moor the aggregate thickness of these rocks is 1,037 feet, consisting of 183 feet of Limestone, 349 of Sandstone, and 505 feet of Shale. A layer of basaltic rock may be considered as forming the base of the Alston Moor mineral strata. In these rocks the metalliferous ores of lead are found to occur. The accompanying section of the strata at Tees-side and Troutbeck mines gives a faithful description of that formation.*

* "The Laws which regulate the Deposition of Lead Ore in Veins on Alston Moor." By William Wallace. 1861.

1. Limestone.	10. Plate.
2. Slaty Hazel.	11. Tyne Bottom Lime.
3. Scar Limestone.	12. Whetstone Beds.
4. Post and Hazel.	13. Whin.
5. Ditto.	14. Hazel.
6. Hazel.	15. Limestone.
7. Plate.	16. Plate.
8. Post Limestone.	17. Jew Lime.
9. Hazel.	

In the Tees-side district a greater thickness intervenes between the top of the Whin-sill and the bottom of the Scar Limestone than in the Garrigill district, but in the latter the whin is considerably thicker than in the former, and the distance in each case between the bottom whin and the bottom of the Scar Limestone is very nearly equal. The copper hazels are also better developed in the Tees-side than in the Garrigill district. At Long Clough mine the firestone stratum is 54 feet in thickness, but not more than half a mile in a north-west direction it only exists as a thin bed of *famp*,* while the ironstone in the same district increases from a few inches to a stratum of a very hard Sandstone 12 or 14 feet thick. The Limestone strata vary but little in thickness throughout wide areas. The beds of Shale vary more than the Limestone, and the Sandstones vary to a still greater extent. The Limestones usually repose upon a bed of Sandstone; if a bed of Shale intervenes it is rarely more than a few inches in thickness.

The original state of the strata over this district was no doubt horizontal, or nearly so. Now the beds are nearly all in an inclined position. This varies considerably, but on the line of the greatest acclivity forms an angle of about 2° 15′. The average bearing of this rise is 30° west of south from the true meridian.†

The following gives a general sketch of the strata of the district:—

The Great Limestone divides the strata into two portions; the upper one consisting of alternate silicious and argillaceous beds with only two thin beds of Limestone, while the under portion contains calcareous strata of considerable thickness.

The Grindstone Sill, about 4 fathoms thick. This is the highest stratum at Allenheads, Coalcleugh, and Rampgill.

The Fell-top Limestone is the first or highest calcareous stratum that occurs in the mining district. It is called the *green Limestone* near Alston. It is too thin to be of consequence in mining, seldom exceeding 4 or 5 feet.

The Crow Coal.—A thin seam of coal of inferior quality occurs under this Limestone. A mixture of this coal and clay is formed into balls, called *cats.*

The Upper Coal Sill.—A silicious stratum varying from 1 to 2 fathoms in thickness.

The Whetstone Sill.—A plate bed of considerable thickness (from 5 to 8 fathoms), and under this another hazel occurs which is used for sharpening scythes.

* A name given to variable beds of decomposed Limestone.

† Thomas Sopwith, "An Account of the Mining District of Alston Moor;" W. Millar, "Mines of Carlisle," 1800; Westgarth Forster, "A Treatise on a Section of the Strata from Newcastle to Crossfell," 1801; Dickinson and Sopwith, "Plans of Holyfield and Hudgill Cross Vein Mines," 1828; Wallace, "Mineral Deposits;"—are the only important publications relating to Alston Moor mining.

The Upper and Lower Slate Sills, commonly called *grey slate*, used for roofing slates and flags, about 4 fathoms in thickness.

The Firestone Sill.—A silicious stratum about 6 fathoms in thickness. Its colour is a coarse reddish grey. Both the earthy and the metallic contents of veins in traversing this stratum attain their maximum specific gravity. Sulphate of barytes is more common in this than in any other stratum in Alston Moor.

Pattinson's Sill lies from 10 to 12 fathoms below the *Firestone*. It derives its name from the miner who first sunk into it at the Rampgill vein. Lead veins have often been productive in it.

The LittleLimestone is the second calcareous stratum in this mining field, lying about 46 fathoms below the Fell-Top Limestone and from 10 to 12 fathoms above the Great Limestone. Mineral veins have often been very productive in this stratum.

The High and Low Coal Sills.—Two hazels accompanied with thin seams of coal of inferior quality.

The Great Limestone.—The thickest Limestone worked in Alston Moor, and by far the most productive in mineral treasures. In the Great Limestone there are three different flats. These flats vary in thickness from 1 inch to 6 feet, and Mr. Leithart, an excellent authority on this district, says: "There have been instances of all the *flats* being so thick at the same place as to form one whole mass of flat from the top of the high flat to the bottom of the undermost one."

The Tuft or Water Sill is about 10 feet thick and is dull-red coloured, containing much oxide of iron. Many veins which have been productive in the Great Limestone have been also productive in this.

Limestone Post.—A thin stratum of impure Limestone about 18 inches thick. This is an equivalent of the underset Chert of Swaledale. Great inconvenience is often experienced in working through this thin stratum on account of the quantity of water which it contains.

The Quarry Hazel.—A dull-red-coloured Sandstone containing some mica, varying in thickness from 1 to 5 fathoms. It has sometimes proved productive of lead. This stratum is sometimes divided by a famp bed, consisting of mica, silex, and argillaceous matter. Beds called *grey beds* are found at the bottom.

Girdle or Till-bed, is a kind of chert, from 3 to 5 yards in thickness, sometimes divided into layers or posts. Veins that have been productive in the four-fathoms Limestone have generally continued so in the till-bed. Mr. Leithart remarks that the metallic contents of the veins in this stratum are usually pure and solid.

The Four-Fathom Limestone derives its name from its thickness, which it preserves more uniformly than any other stratum on Alston Moor.

Veins which have been productive in the *Great Limestone* have frequently proved less rich in lead in this Limestone, but they frequently contain the sulphide of zinc. Many trials have been made in this stratum, but they have not usually been satisfactory; when they have been so, the ore has proved rich in lead, but the lead has not been very argentiferous.

A seam of coal is found under this of about a foot in thickness.

The Nattrass Gill Hazel.—A coarse dull red and white Sandstone. In a mining point of view it is not important, the veins being generally barren.

The Three-Yard Limestone.—A bright blue Limestone containing few, and these generally unproductive, veins.

The Six-Fathom Hazel.—Veins in this have not generally proved productive.

The Five-Yard Limestone.—Impure and flinty veins unproductive in it.

The Slaty Hazel.—Sometimes called Gossop-gate hazel. Very few veins, and those not productive.

The Scar Limestone.—Its thickness is from 5 to 9 fathoms. Its name is derived from the bold precipitous face which it presents, being in many parts most picturesque and romantic. Veins have not proved productive in this Limestone.

The Tyne-bottom Plate is extremely hard. The metallic contents of veins in this stratum are generally dense and pure. Under this is the lowest calcareous stratum exposed in Alston Moor.

The Tyne-bottom Limestone, a hard flinty Limestone. Its veins are rarely productive.

Under the series of strata described appears a range of basaltic rock locally called the *Great Whin-Sill.* It is very variable in thickness.

At Hilton, in Westmoreland, it is 4 fathoms thick.

At Dufton, 7 to 8 fathoms.

At Silverband, 20 fathoms.

At Cauldron Snout, on the Tees, 30 fathoms.

At Tyne-bottom mine, near Garrigill, it is worked into for nearly 20 fathoms.

At Settlingstones, near Haydon Bridge, it occurs at the surface, and the shaft is sunk in it to a depth of 22 fathoms.

This rock is now usually considered as of intrusive origin. Williams, in his "Mineral Kingdom," argued that such rocks were regularly deposited in the same way as the stratified series; but this is no longer admitted. Professor Sedgwick objects to the term *Whin-Sill*, because *sill* indicates a regular stratification of this rock.*

Mr. T. Sopwith says: "The insertion of basaltic rocks among the regular strata at Teesdale is a fact open to the observation of every eye at the waterfall of High Force. In the mine of Silverband, nearly two miles higher up the Tees, the author has descended a shaft sunk through regular strata to the whin-sill, *in which* the miners were then *raising lead ore.* The superincumbent strata here are considered to correspond with those which rise on the *Whin-Sill* at Alston." †

The so-called *Toadstone* of Derbyshire exhibits a very marked similarity to the *Whin-Sill* of Cumberland, and both possess many characters in common with the Elvans of Cornwall.

THE LAKE DISTRICT.—The rocks of the Lake District in England are

* "Cambridge Philosophical Transactions."

† Sopwith, "An Account of the Mining Districts of Alston Moor." 1833. The late Mr. T. Sopwith favoured me with the following remarks on this rock: "The most important igneous rock connected with our lead-mining veins is what is locally called the 'whin-sill,' varying in thickness from 20 to 50 or more *fathoms*, and in this irregular thickness *interposed* over large tracts of country *between* regularly stratified beds of Limestone, Sandstone, and Shales. *Into* this basaltic rock lead veins penetrate or continue downwards from the regular strata, indicating a formation posterior to the intrusion of basalt."

Granites, hornblendic Granites, quartz-felsites, and felstones. These are divided by the late Rev. J. Clifton Ward into several well-defined rocks, which may be thus described.*

The Skiddaw Granite is seen in the course of Sinen Gill, between Skiddaw and Blencathra, and is no doubt connected beneath with the larger mass of the Caldew, a mile and a half to the north. It consists of a white felspar, dark mica, and interstitial quartz.

The *Wastdale Granite*, or Eskdale Granite, occurs at Wastdale head, where it spreads over a small tract at the foot of Kirkfell and Lingmell. The prevailing tint of the rock is reddish, being coloured by the felspar, and the mica is dark. The *Wastdale Granite* sends off quartz felsite (elvanite) in dykes which correspond with the Cornish elvans.

The *Ennerdale syenitic Granite* occupies a large area, is tolerably uniform in appearance, and is usually red in colour, and assumes a more sombre and grey hue from the increased quantity of hornblende and mica, and less decided colour of the felspar; in such cases it is usually more fine-grained.

Diorites.—In connection with the Skiddaw slates and volcanic series are many small bosses and dykes of intrusive rock.

Dolerites, in a very highly altered state, are common. Some of these intrusive rocks are immediately connected with the plumbago mine.

The Skiddaw Slates are traversed by many faults. Most of these have a north and south, or north-north-west and south-south-east direction. It is quite unnecessary to describe here those faults which have no apparent connection with the mineral veins; such as disturb the lodes will be noticed.

DURHAM AND NORTHUMBERLAND.—The Great Limestone has been traced eastward in the Derwent mines to the western side of Cross Fell. It is seen at the surface on the north side of the Tyne, in the mining district of Haydon Bridge, where the beds known as the Tumbler beds are separated from the more compact Limestone by a thick bed of Shale and another of Sandstone.

The following is the section of the strata at Fallowfield:—

SOIL, CLAY, &c.		
1. Plate and girdle beds	42	feet.
2. Grey beds { *Bastard Lime*	11	„
Coal ditto		
Sandstone	12	„
3. Ditto	25	„
4. Sandstone	32	„
5. Grey beds } Ditto coal. } Ditto dark-coloured post	70	„
6. Sandstone	34	„
7. Girdle beds	24	„
8. Grey beds	37	„
9. Hazel	10	„
10. Grey beds	57	„
11. Little or coal lime	17	„
12. Hazel	—	„
13. Grey beds { FALLOWFIELD COAL, 5 feet 8 inches }	20	„

SOIL, CLAY, &c.			
14. Bastard lime		12	feet.
15. Hazel		38	
16. Light-coloured lime		9	
17. Hazel, &c.		69	
18. GREAT LIMESTONE	{ Plate	87	
	{ Lime	38	
19. Grey beds		64	
20. Limestone	{ Plate	72	
	{ Lime	21	
21. Grey beds, *white post*		28	
splint coal		{ 14	
		{ 3	
22. Strong hazel		240	
23. Tyne-bottom lime		24	
Whetstone bed		4½	
24. WHIN		180	
25. Hazel		30	
26. Jan Limestone		24	

In the Magnesian Limestone, in the cuttings of the Stockton Railroad, near East Frickley, these cells are lined with crystals of carbonate of lime,

* See "The Geology of the Northern Part of the English Lake District." By the Rev. J. Clifton Ward. ("Memoirs of the Geological Survey.")

occasionally associated with small but beautiful crystals of sulphide of lead and sulphide of zinc.

In a quarry near Coundon, in the bottom beds of Limestone, they find crystalline nodules of sulphate of barytes, with sulphides of lead and zinc, irregularly deposited through their mass (*Sedgwick*).*

No. 5 is unquestionably a *bed*. The galena is not a water-worn mechanical deposit, but is apparently contemporaneous.

From a quarry (called Seven Acre) between Chesterfield and Well, Professor Sedgwick gives the following section :—

1. Strong yellow cellular Magnesian Limestone, forming base of the quarry . . —
2. Thin shattered beds of a brownish-blue colour, with thin seams of marl . . 12 feet.
3. Earthy, yellowish bands . . . . 3 or 4 feet.
4. Dark brown and black Shale, highly calcareous and semi-indurate . . . 1 foot.
5. Yellow nibbly Limestone, much mixed with earthy impurities, and containing a considerable quantity of *galena* (sulphide of lead) . . . . . . 5 inches.
6. Dark Shale . . . . 1 foot.
7. Yellow Magnesian Limestone (?) . . . . 3 feet.

The following sections of the Carboniferous Limestone series will show position of the Whin-Sill (Fig. 30). The description accompanying the woodcut will sufficiently indicate the position of the basaltic rocks of Northumberland.

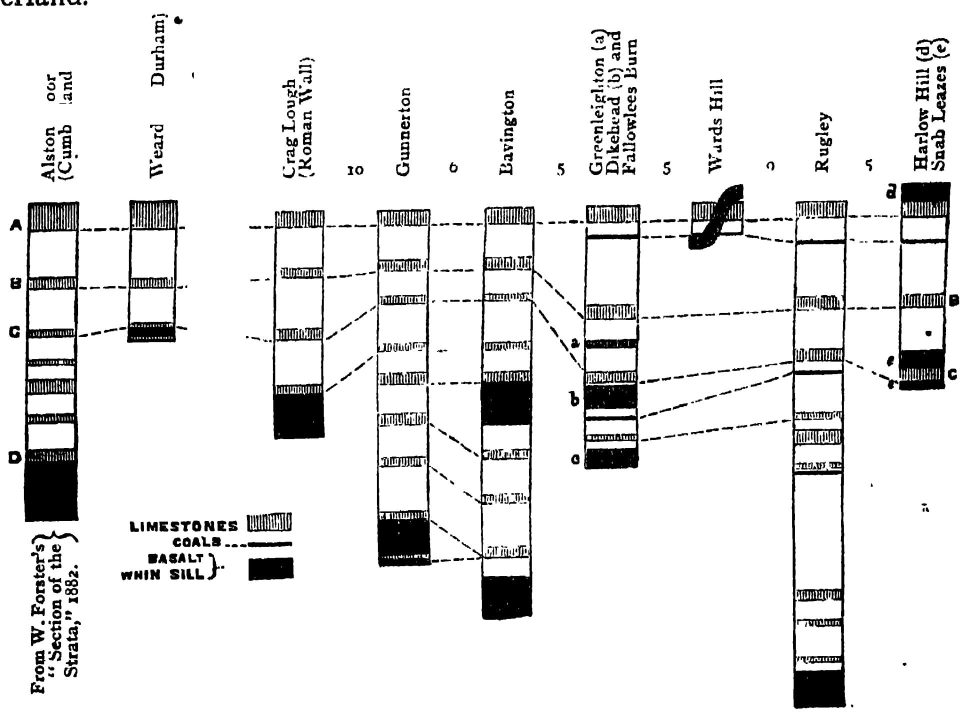
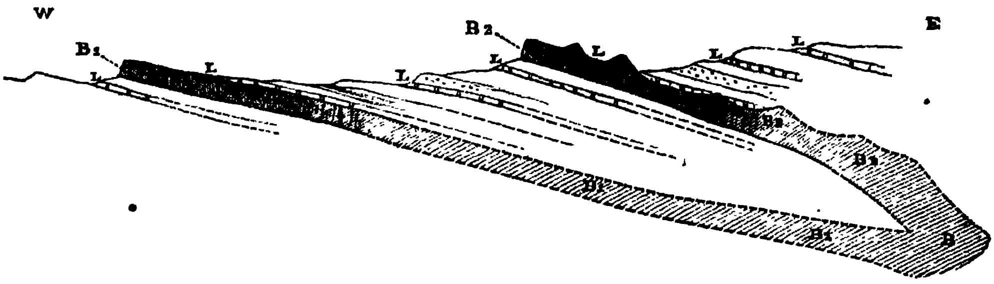


Fig. 30. Sections of the Carboniferous Limestone Series of Northumberland, showing the Positions of the Whin-Sill. Scale 400 feet to 1 inch. The figures give the distances, in miles, between the places. A = Great Limestone of Alston Moor, Weardale, and South Northumberland; the 10-yard Limestone of Alnwick District. B = 4-fathom or 8-yard Limestone. C = 3-yard Limestone of Alston Moor and South Northumberland; the 6-yard Limestone of Mid Northumberland. D = Tyne-bottom Limestone of Alston Moor.

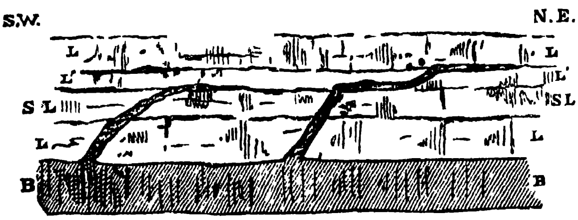
* Professor Sedgwick, F.R.S., "On the Geological Relations and Internal Structure of the Magnesian Limestone," &c. &c. ("Transactions of the Geological Society of London," Second Series, vol. iii.)

The two following sketches (Figs. 31 and 32), which are from the "Geological Survey Memoirs," will serve for comparison with the drawings of the Elvan courses in the Cornish mines. The general conditions will be so evident, that no further description will be required to show the close analogy between these two varieties of Trap rocks as they occur in districts so widely separated as those of Northumberland and Cornwall.



B 1. Western } Whin-Sill.
B 2. Eastern }
L L. Limestone of the Northumberland Carboniferous Limestone Series.

Fig. 31.—Sketch Section across both Branches of the Whin-Sill, showing their probable Mode of Connection near Great Bavington (about 2 miles).



B. Branch of Whin-Sill, 3 to 4 ft. thick (exposed at intervals), sending strings of basalt into the Limestone.
'L. Bed of impure Limestone. L. Good Limestone.
S L. *Saccammina*-beds.

Fig. 32.—Sketch in Elf-Hills Quarry (1st August, 1871).

SHROPSHIRE AND CENTRAL WALES.—A small section only of Shropshire demands our attention. The mineral deposits are confined almost entirely to the Stiperstones range, which Sir Roderick Murchison placed at the base of his Silurian system. Sir C. Lyell groups these rocks under the Lower Llandeilo formation; and Professor Sedgwick calls them *Arenig*; thus the question arises, owing to the absence of fossil fauna, can the geologist draw a definite line between the Stiperstones and the Llandeilo flags, or a vast thickness of rock below which was seen to form the Llongmynd Hills, and was called "unfossiliferous grauwacke?" A glance at the map of the Geological Survey will show that the metalliferous district around Shelve consists of the Llandeilo flags and Sandstone, bordered by the Wenlock shale and the Upper Llandovery rock. It will also be seen that the Llandeilo flags are marked with intrusive masses, with lines of Greenstone, and long intrusive bands of the Felspathic ash. The mineral veins are very irregular, a considerable number running from north-east to south-west, others again from south-east to north-west, and a few nearly north.

If a line is drawn around Shelve for about five miles westward and three miles eastward, five miles to the south and four miles to the north, we include all the important portions of the mineral field.

The geological relations of these districts are of a rather complex

character. In the first place, the Slate rocks are interstratified with great beds of black shale, similar to the carbonaceous shale so frequently met with in connection with mining in the upper beds of the Carboniferous Limestone, which are in the great deposits of lead. Sometimes these shales are mere bands about a yard wide, but at other places they seem to be hundreds of fathoms thick, so that coming upon shale is generally coming upon rich courses of ore. These larger beds of shale have a definite course through the country, in some places occupying large troughs in the Slate rocks. Besides this occurrence of shale we have sudden changes in the character of the Clay-Slate, which favourably affect the lodes. In a rock formation which contains the Stiperstones range it is, of course, by no means surprising that we should occasionally find bands of quartzose matter, and, in fact, certain beds of the Slate rocks not unfrequently become arenaceous in character. Lastly, there are Greenstone dykes and interstratified hornblendic and felspathic bands.

The lead-bearing district of Shropshire is closely allied to that of Montgomeryshire, and, indeed, of Central Wales. The rock in which the lodes of this district occur is of Lower Silurian age, and of that general mineral character which we call Clay-Slate. This Clay-Slate is traversed throughout the whole length of the metalliferous district by that well-known band of interstratified quartzose rock which, from its comparatively greater power of resisting denuding action, stands out prominently above the neighbouring strata, forming the picturesque ridge of the Stiperstones. This ridge bears 30° south to 35° west (true bearing), and dipping north-west; and the lead district is found to be generally in this direction—to the north-west, or direction of the dip of the Stiperstones. About two miles north-west of the Stiperstones, and running nearly parallel with it for some distance, there is the low range forming the Shelve Hill, a little beyond which the lodes seem to die out.

The metalliferous district of Cardiganshire and Montgomeryshire is a tract exclusively of Clay-Slates and Gritstones, corresponding with the lower beds of Murchison's Silurian system. The prevailing strike of the beds is from north by east and south by west, to north-north-east and south-south-west, and in the same direction bands of various widths may be traced, in which many important lead mines have been worked.

This district differs in a striking manner from those in which we have dissimilar rocks. There is not anywhere the appearance of any rocks of igneous origin. All the beds are evidently of one geological age, or rather the differences in the rocks are so slight that it is quite impossible to determine the relative age of any set of beds.

The appearance of the veins at their "outcrop" are so uniform that the miner has no changes of colour, due to decomposition or otherwise, to indicate the riches below.

A tract of land stretching along the sea-coast for about four miles on the north of Aberystwith and twelve miles from Aberaeron is destitute of mineral veins. The high range of mountains to the east and north of Tregaron, of the chief group of Plymlymon Fawr, of the hills east of Llanidloes, and of the plateau between that town and Llanbrynmair, are in like manner distinguished by the absence of mines. A portion of the two counties

being thus distinguished, varying in lithological character from a soft shale and argillaceous rock to a coarse gritstone and conglomerate, is free of any mineral deposits. The productive mines are generally parallel to the run of the undulations of these rocks. These zones may be divided into six groups, which are thus satisfactorily defined by Mr. W. W. Smyth, who, as mining geologist to the Geological Survey, examined with the utmost care this interesting district* :—

"The first group, beginning on the west, borders on the unproductive grits of Aberystwith, and includes the mines of Tal-y-Bont, Penybontpren, Llancynfelyn, and Tre-'rddol, producing lead ore containing a very trifling amount of silver, a little zinc-blende, and in two or three instances copper pyrites. The lodes are of small width, and the strata, with a moderate westerly dip, are perpetually running into the fissile variety of slate, which injures the regularity of their metallic contents.

"The second is a band of greater importance, which about two centuries ago, when known as the 'Welsh Potosi,' returned enormous wealth to the enterprising adventures of Sir Hugh Myddleton and Mr. Bushel, while at the present day it is distinguished by the mines of Goginan, Cwm Sebon, Cwm Symlog, Daren, Pen-y-Cefn, and Esgair-Hir. The Slaty rocks here assume a paler tint, inclining to a bluish and greenish grey, offer a peculiar and almost greasy lustre and exhibit on the whole a more massive bedding, in consequence of which it would appear that the mineral veins increase in width, expanding in some cases to upwards of 20 feet; the lead ore is generally argentiferous, sometimes to the amount of 38 ounces in the ton of lead.

"The third division, ranging from Ystrad Meyric to the Devil's Bridge, and along the course of the Rheidol, comprehends a number of mineral veins, varying in character nearly as much as the rocks which they traverse; thus Llwyn Malys lode is remarkable for containing a small percentage of silver, though at a distance from other argentiferous mines; Fron-Goch for its large deposits of galena and zinc-blende; the Estymteon lode for its bands of iron pyrites; and that of Pen Drosgol for its manganese ore; whilst the beds exhibit every variety between the Gritstones of the Mynydd Bach and of Drosgol, the dark fissile Slates on which various quarries have been opened, and the indurated grey argillaceous rock in which the mines generally occur.

"The fourth band, striking from Lampeter to the central range of Plymlymon, will include the highly argentiferous lead lode of Llanfair Clydogau, and then, after an interval of some miles on the north, several of the localities most productive of common lead ore, accompanied by zinc-blende and calcspar, the principal mines being known as Esgair-y-Mwyn, Logaulas, and Nant-y-Creiau. To the north of Plymlymon Fawr, where the beds for the most part consist of fissile shales and gritstones, not a trace of ore has yet been discovered.

"The fifth zone, ranging along the east of the Plymlymon ridge, comprises the remarkable and extensive mines of Cwm Ystwith, some slightly worked veins in the upper valleys of the Wye and Severn, the important works of

* "On the Mining District of Cardiganshire and Montgomeryshire." By Warington W. Smyth, M.A., F.R.S., F.G.S. ("Memoirs of the Geological Survey of Great Britain," vol. ii. part 2.)

Delife and Esgair Galed, and the group of parallel lodes near Llanbrynmair. Beginning with the elevated mass on which the Teifi pools are situated, the southern part of this division is marked by a frequent intercalation of arenaceous matter, which to the north of the Delife mines is succeeded by argillaceous shale; whilst it is remarkable that, throughout the former area, copper pyrites is so common a constituent of the lodes as to have been separately returned from several of the mines, as Copper Hill (Cwm Ystwith, Siglen Las, Hafod Feddgur, Cwm Rhicet, and the Delife.

"The sixth division, circumscribed as it is on the east and north by the gritty beds which crop out from beneath the Wenlock shales, comprehends a few mines round Llanidloes, as Byrn Dail, Pen-y-Clyn, and the Gorn; but these are characterised by the remarkable fact that the ore of lead is accompanied by witherite and baryte, neither of which minerals have yet been met with in any other part of the district we have considered.

"In the same zone might be included another group of plumbiferous veins occurring in a remote part of the county around Llangynnog, at a distance of nearly thirty miles from those above mentioned. They traverse the Slaty rocks where they emerge, in their regular line of strike, from the superincumbent grits which form the dreary tract dividing the drainage of the Dyfi from that of the Fyrnwy and Banw; * and their relationship is further proved by the ores of lead and zinc being associated with the same minerals of baryta. An essential difference is, however, to be remarked in the frequent intercalation of beds of felstone porphyry and gritty rocks of volcanic origin among the Slates, a fact which bears in a marked manner on the distribution of ores."

The lead-mining district of Shropshire is geologically a part of the great mining district of Montgomeryshire, the resources of which are best shown by what has been done by the Van mine. As to the district itself, we have no hesitation in saying that for its extent—for it is only a small district—it is unsurpassed by any district in the United Kingdom, or as a lead-mining district probably in Europe. The most important mine is Snailbeach, which has been worked ever since the last century, and has made immense profits for about ninety years, having on an average raised 2,000 tons of lead ore a year. It may be considered as one of the most important lead mines in the kingdom. Although a few years ago Minera, in Denbighshire, was a richer mine, and at present Van, in Merionethshire, is so, yet taking into consideration the permanence of its working, and the length of time it has been making profits, it will probably be found that Snailbeach has yielded larger returns than any other lead mine in England.

Adjacent to this is Perkin's beach mine, where, some years ago, a fine deposit of lead was found near the surface, and 3,000 tons of lead ore were raised out of the workings, which were then about 70 fathoms deep. There are four principal veins in this mine, which run a little to the *north of east* and to the *south of west*, with a southern underlay. There are also four powerful caunter veins running very nearly *north* and *south*, with south-westerly underlays, each producing ore. The first, second, and fourth veins run parallel

* "In this district, also, a few metalliferous veins occur in the region of the arenaceous rocks alluded to as at Moel Vchlas, near Can Office and Bwlch Creolem, near Llangynnog: but the trifling operations hitherto carried on upon them yield no data of importance."—W. W. S.

to the Snailbeach lode, which has been worked with much profit for more than fifty years.

The first and second caunter lodes are bold and well defined. From the latter upwards of 600 tons of ore were raised in a very limited space, in the back of the deep adit level. More than 200 tons have also been obtained from the first caunter lode.

The Adit Mouth vein is also a very good one, Pugh and Gwilliam's sump being on it, from which a great deal of ore has been got. Good ore was cut it crossing through it north from the Big Spar vein which intersects Cross's.

The Big Spar vein is a great champion lode that can be traced on the surface from the extreme east of the mine to and beyond the boundary of Oven Pipe, an adjacent mine. It is composed of lime-spar and sulphate of barytes and spots of ore.

On Cross's lode upwards of 2,000 tons of ore were got from the surface to about the middle adit level, and the pipe of ore made rich up to the sod. In a point about the middle adit the surface pipe of ore forked, owing to the Elvan, in which it was, being interfered with by the blue Slate which entered the vein, and threw the so-called *Elvan* north. The general opinion is that the ore was carried north with it, and would be found on the lying walls of the lode.

In the middle adit, to the east of the engine shaft, the lode is so wide that one side only of it has been removed. It is composed of a soft, decomposed, probably igneous rock (locally called an *Elvan*), and continues in the same direction up to the surface.

There is another vein, called Birch's lode, lying to the east near Stiperstones. It is a kindly well-defined parallel lode. The mine is situated on the north-west slope of the Stiperstones range, bounded on the east by Snailbeach, and on the west by Oven Pipe and Pennerly mines. The strata in which the veins are imbedded is a finely-defined Clay-Slate, with a large deposit of a rich metalliferous rock. The workings of this mine were for a time suspended, but have recently been resumed.

Oven Pipe, the adjacent mine, is also rich in lead ore; another equally rich mine in the same district is Roman Gravels, which is probably the most ancient lead mine in Britain, having been undoubtedly worked by the Romans. Through the Middle Ages we have records of its having been worked at intervals, and of its yielding large profits. It is still active; and although it cannot be considered one of the best lead mines, it is good, and may be ranked with West Chiverton in Cornwall and the Lisburne mines in Wales.

There are many more lead mines in this district than those already mentioned, but the above are the principal ones. The length of the metalliferous district skirting the Stiperstones is about six miles, while that of the district skirting the Shelve Hill is only about three miles.

The mines working in Shropshire in 1881 were the following:—

Roman Gravels, producing lead ore	2,921	tons.
Snailbeach ,,	1,946	,,
Tankerville ,,	542	,,
East Roman Gravels ,,	440	,,
Pennerly ,,	25	,,
Bog ,,	15	,,
Perkin's Beach ,,	8	,,

CHESHIRE.—The *New Red Sandstone, or Trias*—with the exception of a strip of *Permian*—composes the whole county of Cheshire west of the Red Rock fault. The "pebble beds" consist of liver-coloured quartz with white quartz, hornstone, and grit. The finest section in these beds is seen on the banks of the Mersey at Stockport. *The Upper Mottled Sandstone* has a thickness of about 600 feet, and rests on the pebble beds. This stratum may be distinguished by the entire absence of pebbles and the finer grain of the particles of sand.

The Lower Keuper Sandstone and *Waterstones* is the massive quartzose conglomerate which forms the escarpment of Alderley Edge. This conglomerate is formed of rounded pebbles of white and coloured quartz very similar to those of the pebble beds of the *Bunter Sandstone.* In looking at the Alderley Edge rocks we are strongly reminded of the cliffs of white conglomerate which form the base of the Keuper series along the valley of the Churnet, in Staffordshire. At Alton, however, the conglomerate of the Keuper rests on the pebble beds of the Bunter (Fig. 33), and here on the Upper Mottled Sandstone, making the contrast striking. In some places, at the junction of the Keuper and Bunter divisions, a band of marl occurs, giving rise to springs. One of these may be seen on the north side of the Edge, but the same band occurs in much greater strength at the Old Copper mine on the east of the Edge. The beds which succeed the

Fig. 33.—Cliffs of Conglomerate on Alderley Edge.

conglomerate are formed of white and variegated Sandstone, from which the copper ore of Alderley Edge was obtained. The same bed occurs in the escarpment above *Clockhouse Wood Farm.*

In Mr. Henry Holland's "General View of the Agriculture of Cheshire," published by the Board of Agriculture, we find an account of the progress of mining at Alderley Edge: "This hill forms a striking feature on the

eastern side of the county of Cheshire, rising gradually from the south-east, and terminating abruptly towards the north by a precipice of 300 or 400 feet in height. A Sandstone rock breaks out in many places on the summit and northern side of the hill, having an inclination from south-west to north-east, at an angle of 14 degrees with the horizon. Some of the strata of this stone are 3 or 4 yards in thickness, and are separated from those above and below by thin seams of marl, here and there tinged with a slight colouring of copper. The stone is in great repute for building. Lumps of marl are, however, sometimes met with even in the most solid blocks, and still more frequently the rock abounds with pebbles of quartz bedded in it in all directions. There appear to be three or four great breaks or interruptions of the Sandstone strata in the structure of the hill. These extend across it from east to west, and are filled irregularly with Sandstone and masses of sulphate of barytes, amongst which are many veins of lead and copper, in some places distinct from each other, in others so mixed as to render it somewhat difficult to ascertain, from mere observation, which of the two metals predominates (Fig. 33). Some specimens of very rich lead ore have been obtained, but on the whole it is poor, and is, as well as the copper, intimately mixed with the grit or Sandstone. Some ore of cobalt has also been met with. The veins of all these metals approach very near the surface, and have been found to ramify with increasing richness to a depth of 30 or 40 yards. In all probability they extend much further into the body of the hill.

"About a century ago Mr. Abbadine, a Shropshire gentleman, cut a tunnel, 1 yard wide and 5 feet in height, half through the hill, at the depth of about 30 yards from the highest surface. He met with nothing but the Sandstone until he arrived at the centre; and finding there that the valuable part of the ore was considerably below the level of his tunnel, he abandoned the enterprise. Since that time different companies have engaged in the same speculation, and have driven tunnels and sunk shafts into various parts of the hill, but without finding an ore sufficiently pure to render the mine valuable. One company who undertook it was formed by Mr. Rowe, of Macclesfield, who was at the head. This gentleman was at one time very sanguine in his expectations of success, and kept not less than forty or fifty men constantly employed; but upon the discovery of the great body of copper ore at the Parys mine, in which he was engaged, he suddenly gave up his concern at Alderley Edge, and took all his miners with him into Anglesea."

After this time no search for copper or lead was made in the hill until some few years since, when, upon the unexpected discovery of a few veins of good ore at the extremity of the old works, some gentlemen of Stockport were induced to recommence the speculation. Their prospect of success appeared good; large quantities both of copper and lead ore were obtained, and they erected works for preparing and smelting it.

At Mottram St. Andrew, a mile or two to the north-east of Alderley Edge, in the lands of Lawrence Wright, Esq., both lead and copper ore have been met with. Intermixed with the Sandstone, which is the matrix of these ores, some cobalt ore has been found.

"Alderley Edge and its neighbourhood are not the only places in Cheshire where copper ore has been met with. It has been long known to exist in the Peckferton Hills, which form the southern part of the tract of high ground running across the middle of the county. Here it has been worked irregularly at different times; but from the small quantity obtained, and its inferior quality, the speculation was not attended with profit to the proprietors. I understand, however, that a vein has lately been met with in these hills on the estate of John Egerton, Esq., of Oulton (recently the property of Sir Malpas de Grey Egerton), from which there was every prospect of obtaining a considerable quantity of valuable copper ore" (*Holland*).

Smalts was at one time prepared from the cobalt, but eventually the Excise surcharged the manufacturers for glass duties, and the chemical works were stopped.

The late Mr. Molyneux, of Burton-on-Trent, discovered a similar deposit of copper in a mound of Sandstone on Cannock Chase, in Staffordshire.

Similar deposits of cupiferous Sandstone were found at Grinshill, near Shrewsbury. They were worked first by W. Wright, Esq., and subsequently by a copper company of Birmingham, who expended a large sum of money upon the spot, but did no good. With these deposits there was a certain quantity of the black oxide of cobalt. A similar bed was found at Pims Hill, as well as other places, but no quantity has been discovered anywhere but at Alderley Edge. There is silver in some of those strata: a grey copper ore from one of them gave 320 oz. of silver per ton, but in the carbonates not more than 1 oz., per unit of copper, has been found.

Galena has also been observed in the strata of the lower Coal Measures at Whaley. Veins of lead ore have been worked both above and below the *Red Ash* mine. The largest quantity of ore has been obtained from the colliery in the rock below the Red Ash, although the lode itself has been traced through all the strata down to the *Big* mine. The position of this will be seen from the following section:—

SECTION IN LOWER COAL MEASURE, NORTH OF WHALEY.

	Ft.	in.
Marl (*boulder clay*)	60	0
Shale, with "Flags"	80	0
Black shale, *with fossils*	10	0
Coal (Red Ash mine)	1	6
Rock (*with vein of Galena*)	24	
Shale, *with fossils*	36	
Coal (Smithy mine)	1	
Strata, *principally rock*	30	
Coal (Cannel mine)	1	
Rock and shale	30	
Woodhead Hill Rock	21	
Shale	39	
Coal (Big mine)	3 feet to 4	

The ore was chiefly confined to the rock below the *Red Ash* mine, in which the lode was 24 inches wide, and yielded from 60 to 70 lbs. weight per dish of ore. The lode "perished" in the centre of the basin, but southward became very rich, and has now been worked out. In the *Big* mine the lode occurs as a small fault, and contains small pieces of lead ore.*

* "The Geology of Stockport, Macclesfield, Congleton, and Leek." By Edward Hull, F.G.S. and A. H. Green, F.G.S. ("Memoirs of Geological Survey," 1866.)

North of Hareshill, resting on the *Upper Mottled Sandstone*, these deposits are repeated by a large fault, and also at the copper works at Mottram St. Andrew. Sections in the same beds occur in the Banks of the Bollin at Quarry Bank, near Wilmslow, the beds dipping westerly at angles varying from 15° to 30°.

The following is given by Mr. Edward Hull, of the Geological Survey, as a summary of the order of succession of the *Lower Keuper Sandstone group*, as it occurs in the neighbourhood of Alderley Edge and Wilmslow :—

	Thickness.
Waterstones—flaggy micaceous brown Sandstones and Shales	150 feet.
Freestones—white and brown, for building	100 „
Sandstones—soft white, yellow, or red	100 „
Conglomerate—white and reddish	100 „
	450 feet.

From the same authority we derive the

SECTION AT THE ALDERLEY EDGE MINES.

	Ft.	in.
Thin Sandstone	4	1
Shaly clay—*with a band of copper ore at bottom*	2	6
Ferruginous Sandstone—with nodular masses containing *carbonate of lead*	6	0
Cobalt bed—laminated Sandstone, with cobalt ore	4	6
White compact Sandstone—with *carbonate of lead*	5	0
Ferruginous Sandstone—with manganese and cobalt	12	0

It must be remembered that the copper occurs disseminated through the clay or Sandstone, in a very minute state of division (very small concretionary masses, like fine shot), as green and blue carbonate, the differences in colour being determined by the water it contains. The sulphide of lead—*galena*—and the carbonate of lead are found in the same disseminated condition.

In the centre of the works a deep hollow cut in the Sandstone occurs. This is filled with boulder clay, and is 40 feet in depth and 180 feet across the top. The author visited Alderley Edge accompanied by the late Lord Stanley of Alderley, and made several sections of different parts of the workings. This examination rendered it evident that the raised position of the Edge is owing to the existence of a large fault which runs along the base of the hill on the north side. Mr. E. Hull, however, remarks: "It is difficult to understand why the Sandstone rocks of Alderley have been allowed to remain elevated, while the Sandstone rocks of the contemporaneous beds at Mottram, Wilmslow, and other places have been denuded down to the level of the red marl and Bunter Sandstone."

The solution of this problem depends entirely upon the answer which we give to another. How and when, in geological time, did the bed on Alderley Edge become impregnated with mineral matters? The beds forming the Edge were deposited at very different times, or they were impregnated with their mineral contents at times clearly separated. The beds are not sharply marked off from each other, but they pass by a delicate shading from copper to lead, and from lead to copper.

A careful search leads to the belief that the source from which these deposits, or one of them, has been derived is close at hand. About the highest portion of the Edge there is a fissure about 3 feet wide, and it may be rather more than 30 feet in length. In passing through it, the side walls were seen to be evidently those of a mineral vein, being—though

irregular—quite smooth. This fissure, which had been cleared out, from the way in which it contracted at the bottom, was, evidently, the thinning out of a vein. After much careful thought, the conclusion arrived at was that at a remote period mineral veins of copper, lead, &c., existed on Alderley Edge, and that the contents of those veins had been removed by denudation, the metallic matter in solution being filtered, through the sand beds lying lower down on the hill. The lodes of copper and of the lead may have been at different levels, and consequently exposed at different times to the action of water or air (the decomposing agent), so that at one time the natural filter-beds were receiving solution of copper, at other times solution of lead, &c.

Lord Stanley of Alderley stated that in some of the ploughed fields slags were frequently found. On this occasion we had not far to seek, and many copper slags were discovered. The quantity of copper in those slags indicated that the smelting operations formerly carried on were of the rudest kinds. This renders it probable that the veins which formerly existed on Alderley Edge were worked by some ancient people. By their operations they laid bare the veins of lead and copper, and this at all events accelerated that decomposition to which the deposits in the Sandstone are due.

FLINTSHIRE.—If we suppose a complete cutting through the carboniferous strata which would show the different elements composing it, we should find in dividing the clays and the Wenlock shales, from the Devonian Freestone (Old Red Sandstone) on which it rests, the following series:—

1. White or Mountain Limestone.
2. Black Limestone, including hydraulic Limestone, known under the name of Aberthaw.
3. Blue Limestone.
4. Chirt or chert.
5. Shale.
6. Gravel.
7. Alterations of shales (schists) and of freestones, Sandstones, "post," &c.

1. The white Limestone is always very clear, and its colour varies from greyish to pale yellow.

2. The black Limestone, as its name implies, is very deeply coloured, and often attains a black. It is an argillaceous Limestone, and is frequently bituminous.

3. The blue Limestone is sometimes found in a hard state and in thin beds, yellowish or grey-blue, filled with encrinites, sometimes in a state of very argillaceous schists without consistence, and blue-black in colour.

4. The chert is formed almost exclusively of silica. Its colour varies from the deepest black to clear grey, sometimes streaked with reddish tints.

5. The shale is a black schist, harder than the blue schists.

6. The gravel consists of rolled pebbles, the dimensions of which are small, with all the variations between pebbles and sand, the whole more or less agglomerate and compact, according to the locality.

7. The freestones, &c., are the finely-stratified Sandstones, compact and of a yellow colour.

Our knowledge of the lead-mining district of Flintshire owes much to the long and continuous examination made by M. Moissenet, lately Professor of Mines in the École des Mines in Paris, and in our examination of the filling

of the mineral veins we shall borrow from his labours. Before we quit this division of our subject the celebrated well at Holywell, which bears importantly on the mineralogy of the district through which it flows, must be described.

The town of Holywell has received its name from this powerful spring, which is very abundant at all seasons, and which rises with great force at the foot of a mountain. The volume of water attains 100 cubic metres a minute, but, contrary to the superstition of the inhabitants, it suffers a considerable diminution in the summer. This spring is held in great veneration in the country, especially by Roman Catholics, and is reported to have effected numerous cures: the proofs of which are suspended in the form of crutches and other votive offerings in the church constructed over the basin. The water of the well is hard, and the temperature is nearly always equal.

Thanks to the steepness of the valley, they have been able to form successive reservoirs, from the well as far as Greenfield, between which have been erected several establishments which receive the motive power of the falls thus created. (A woollen factory, Newton and Keates's lead and copper works, and a flour-mill, &c., are worked by its water.) It is at these places that the diminution of the supply in summer is perceived.

The fissure through which this well flows will be seen by the geological map of Flintshire to commence in the southern part of the large mass of Carboniferous Limestone near the mouth of the Dee, near Prestatyn. This Limestone on its eastern edge contains a great number of metalliferous veins through its entire length. The veins, however, sometimes occur in the Millstone Grit. On the western side of the Limestone there are but few mineral lodes, and these occur principally between Diserth and Meliden.

DENBIGHSHIRE.—In Denbighshire we find the Mountain Limestone extending from the Flintshire rocks along the western edge of the Coal-basin to Llanymynech in the south. With a few very unimportant exceptions, the mineral lodes are confined to the northern extremity. We find in that locality a series of very remarkable *faults*, their general direction being north and south. One extensive fault, however, running from the west of south to the east of north, produces a great disturbance between the Limestone and the Millstone Grit. The Minera lode is the most remarkable, and has been worked more extensively than any other in the district. This, according to the Geological Map, extends from the coal-field which it penetrates a distance of between four and five miles, from the south of east to the north of west. Upon entering the Limestone on its eastern side a marked deviation occurs, a branch starting off nearly westerly, and being continued beyond the great fault merely as a non-metalliferous fissure. The lodes to the south of Minera have the same general direction, but these are but a few small veins running due east and west.

CARNARVONSHIRE.—*The Great Ormes Head* is a mass of Carboniferous Limestone, in which four lodes occur which all run parallel with each other north and south. The Limestone beds in some places have a crystalline character, which appears to claim a relationship with the copper-bearing veins, for, except when surrounded by a crystalline rock, the veins are scarcely seen to exist, and are never productive. The crystalline beds and

the non-crystalline alternate with much regularity, and the metalliferous character of the veins changes in a striking manner in crossing those beds. The leading veins are sometimes intersected by cross veins, which are often favourable to the production of copper ore, especially where the intersection occurs in a crystalline bed. The ore is then found to extend through the whole group, constituting a large deposit of copper pyrites.

Sir A. C. Ramsay, who has carefully studied the district of Snowdon, draws attention to the numerous faults which penetrate the Greenstone and the Silurian Slates: "Where they most concentrate on the north-west of Glaslyn several of them—the faults—are copper lodes, one of which, generally striking to the north-west and branching out in various directions, has been worked at intervals and yielded a considerable quantity of yellow sulphide of copper."

Copper ore was also found in the neighbourhood of Dolgelly—in Vigra and Clogau—associated with gold. About half a mile west of Dol-y-Frwynog the once famous Turf copper mine was situated in the heart of the talcose schist. Iron pyrites in small crystals is scattered through the rock, together with specks of yellow sulphide of copper. A peat bog occupied the greater part of the bottom of the valley. This was found to be impregnated with sulphate of copper. By burning the peat moss large quantities of copper were separated.

In the long valley that stretches between Cwm Dyfor and Brynhir bands of grit appear. These are all overlaid with dark blue Slate; they are much faulted, the cracks sometimes containing a little copper ore and much iron pyrites. A little copper pyrites has been occasionally worked near Llyn Peris, not far from the pass of Llanberis.

Drws-y-Coed copper mine and Symdde Dylluan, in the Vale of Nantlle, near Carnarvon, occurring in the Silurian Slates, have produced considerable quantities of copper ore. When these mines were visited some years since, the author was impressed with an idea that the metalliferous deposits were not real lodes, but rather, thin beds spread out in the bedways of the Slate rocks. They are, however, marked as lodes in the Geological Maps, having a direction from the south of west to the north of east.

In the neighbourhood of Llanrwst, in connection with the intrusive beds of Felspathic rocks and Quartz Porphyries, numerous lead lodes occur. They generally have a north and south direction, but two or three of the lodes run east and west. There does not appear to be any difference in the metalliferous character of the lodes which can be traced to have any dependence on their direction.

In describing the rocks of Snowdon, Sir A. C. Ramsay, speaking of the *faults*, writes:—

"It is scarcely necessary to enter into all the details of the effects produced by the faults drawn on the map of other parts of Snowdon. . . . . Where they most concentrate on the north-west of Glaslyn several of them are copper lodes, one of which, generally striking to the north-west and branching out in various directions, has been worked at intervals and yielded a considerable quantity of the yellow sulphuret of copper (sulphide of copper)."

After describing many *faults*, he continues: "Another, which passes

along the south side of Crib-Goch towards the copper lode, throws the *upper* columnar felstone down upon the ashy beds. . . . . A branch of this fault which cuts through the Greenstone to the south-east is a copper lode, and has been occasionally worked."

GOLD.—The gold-producing rocks of the Dolgelly district in North Wales require, from their peculiar character, more than a passing notice.

Mr. A. Dean, who first drew attention to those auriferous deposits, has favoured us with the following remarks:—

"A line drawn from the junction of the Hirgum brook with the river Mawddach, to the village of Festiniog would represent the great north and south anticlinal axis of upheaval and fracture in the district, and the longitudinal axis of a rough ellipse about 15 miles long by 12 miles wide. Those limits would enclose nearly all the mines opened in the locality. Outside, to the eastward and north, other fields are found, the most promising being the Bala district, in which is situate the Castell Carn Dochan gold mine.

"Along the longitudinal axis before mentioned, the strata dip from the centre towards the north and to the south, and fall off also to the east and the west. The great central boss or dome is occupied by beds of Cambrian Sandstone and Slate, whilst the lower beds of the Lower Silurian formation form the surrounding margin.

"In the Lower Silurian beds nearly all the gold mines are opened, but some quartz veins in the Cambrian Sandstones also produce gold. Great numbers of floors or beds of Greenstone or '*Elvan*' are enclosed in the beds of Silurian Clay-Slate, and trap-dykes are of frequent occurrence in the Cambrian as well as the Silurian beds. Away from the vicinity of the Greenstone or trap-rocks no good gold lode has been discovered. The Greenstone beds frequently become so much laminated both at the surface and in depth as to be scarcely distinguishable from the surrounding sedimentary beds.

"The whole district is remarkable for the great number of cross courses and faults which traverse it. Their frequent intersections with the auriferous quartz veins is advantageous to the latter, as the concentrations of auriferous minerals are most frequent in contiguity to the cross courses, &c., more especially upon the dip side of the latter. The auriferous quartz veins have generally a direction a little south or north of east and west, although gold has been met with in considerable abundance in veins running nearly north and south, and at Tyddyngladnis mine a lode bearing north-west and south-east contains much sulphide of silver, as well as gold associated with lead ore, blende, &c. This lode traverses Cambrian as well as Silurian rocks. The Silurian beds traversed by the gold lodes are very various in character; those which are hard and sharp and well silicified are the best for gold, and the soft beds are unfavourable to the production of rich auriferous minerals in the veins.

"When the Clogau St. David's mine became rich in gold a rush for gold-mining set in, and every quartz vein, without regard to the rocks in which it was enclosed, was pronounced to be auriferous. This has led to much disaster, as a great number of workings were commenced in ground which

offered no chances of success, and would at once have been condemned by any person really conversant with the peculiarities of the local formations. The country and gold-mining were so new to the great majority of the persons charged with the working operations, that great mistakes were inevitable. Nevertheless, there are good gold mines in the district, and it is to be hoped that past experience will enable the proprietors to reap the reward of their enterprise.

"Nearly all the auriferous veins carry lead, copper, blende, and other ores sparsely disseminated through them, and with those ores the gold is intermingled through the quartz. Any quartz vein not containing iron pyrites, blende, or copper ore will generally be found worthless for gold. During several years numerous attempts were made to work some of the lodes for the common metalliferous minerals, but in only two or three cases with success. At that time the existence of gold in the lodes was not even suspected.

"The presence of so many various minerals has, in many instances, rendered the extraction of the gold from the quartz a matter of much difficulty. The improved processes now in course of adoption will probably overcome the mechanical and chemical obstacles to the desired extraction. The reduction machinery employed at several mines was wholly unfitted for the work to be done, even if the ores had been of the most simple kind. To the novelty of the work to be carried out, to inexperience, and to bad selection of sites for mines, may be attributed much of the disappointment and loss which has occurred from first attempts at gold-mining in Wales. The number of failures in every mining district, whether the mineral sought be lead, tin, or copper, are probably quite as great in proportion to the successful enterprises, as those which have occurred in Welsh gold-mining.

"For the extent of ground wrought, the Clogau St. David gold mine has probably produced as large an amount of value and profit as any tin, lead, or copper mine in the kingdom, and there is no reason to believe that other mines equally rich are not to be found in the district. Indeed, the Clogau Company are now opening a new mine, which promises to become very shortly quite as good as the one before mentioned.

"Until lately the discovery of rich bunches of gold was the one object for which the mines generally were wrought, and no attempt to reduce the poorer ores was made. The Clogau Company has stamped 2,500 tons of poor ores, yielding an average of 12 dwts. per ton; and during several months the Castell Carn Dochan Company stamped 200 tons of the mineral broken indiscriminately from their lode, with an average of 15 dwts. of gold per ton of stuff. With good reduction machinery several of the gold mines in the Dolgelly district might be made to pay."

ANGLESEA.—The following statement of the chief features of the geology of Anglesea is derived from Sir A. C. Ramsay's work on "The Geology of North Wales." The long experience of this eminent geologist, and his habits of close observation, give a value to his description of the rocks of a country which cannot be improved upon. The Cambrian rocks of Anglesea were disturbed before the deposition of the Arenig Slates, which lie uncon-

formably upon them, and which are, it is supposed, overlaid by the Llandeilo and Caradoc beds.

The Silurian rocks, forming the central part of the island, were metamorphosed by the action of a broad tract of imperfect Granite, which crosses Anglesea from north-east to south-west. Some questions arise in connection with this hypothesis of metamorphism, which certainly require an interpretation which they have not yet received.

On these rocks the Old Red Sandstone lies quite unconformable, having, in the absence of the Upper Silurian strata, no passage or direct connection with the Silurian strata below.

"It seems to me," says Sir A. C. Ramsay, "after long and minute acquaintance with Wales, that what is now Anglesea and the neighbouring low-lying parts of Carnarvonshire (and much more besides, now partly wasted by denudation and partly covered by sea) was a low undulating country, which by degrees got deeply buried under the Old Red Sandstone, and Carboniferous strata, so that the whole of what is now the island, and wide regions beyond, were altogether concealed by these overlying strata.

"At a later date the Coal Measures and underlying strata were so far upheaved that the Coal Measures suffered great waste and denudation, and the Permian strata were deposited unconformably upon them as part of a wide-spreading salt lake."

GRANITE, said by Dr. Berger not to be the genuine old Granite, occurs along the slope of Dun-how, on the road from Laxey to Ramsay. A similar small Granite is to be seen at Dun-bridge, where it comes to the surface at 300 or 400 feet above the sea-level. Another small-grained Granite is found in the Foxdale lead mine, nearly in the middle of the island, 346 feet high. At 40 yards deep the Granite was found to form the north "cheek," or side, of the vein, the galena adhering to it. This rock was of a coarse-grained texture, with reddish and decayed felspar, and plates of white mica.

CLAY-SLATE is limited to the high ground occupying Snafield (or Sneifeldt) and other hills. Bishop Wilson determined that the height of Snafield, "by an exact barometer," was about 580 yards. Slate also occurs at Mount Pellier as hornstone, and at Peel-hill and Balla-gawn as roofing-slate.

GRAUWACKE may be traced all along the contour of the island, forming a range of bold cliffs. Near Laxey there is a grauwacke Slate, used as flags for flooring houses. Thin coatings of an ash-grey colour spread over the surface.

LIMESTONE lies conformably over the most superficial of the produced strata of grauwacke, but the dip became less as the strata retreated farther back from the land into the sea. It may be comprehended between 10° and 20°. This secondary Limestone is accompanied by the Magnesian Limestone. These occur in separate beds.

ISLE OF MAN.—*Porphyry*, *Sienite*, and other primitive rocks occur in the island. For the following remarks we are indebted to the late Rev. J. C. Ward, who was for many years attached to the Geological Survey, and to

this gentleman we are under obligations of no common kind for a most accurate survey of the Lake District of Cumberland.

This geologist found, in contrasting the physical history of the Isle of Man with that of the Lake District, that the earliest records of both areas are of about the same age, the deposits in both cases indicating a generally shallow sea, in which muddy and sandy strata were laid down. He concludes his memoir * in the following words:—

"While this state of things was interrupted in Cumbria by an outburst of volcanic violence, sub-marine eruptions passing into sub-aerial, we have no direct evidence to show that such was the case over the present area of the Isle of Man, though it is probable that some of the finer volcanic ash was at any rate occasionally wafted for many miles westward. That this area, in common with that of Cumbria, underwent elevation, accompanied by denudation, in post-Silurian and pre-Carboniferous times, is at any rate probable, and, as in Cumbria also, the early-formed Carboniferous strata were deposited around a Silurian nucleus, the embryo Isle of Man. At this time, off the shores of that early Mona, submarine volcanic eruptions recurred, synchronous or approximately so with other like eruptions occurring farther northward over the present area of Scotland. There is no evidence of any such action taking place around the shores of the Cumbrian nucleus, although there are, south of Ullswater, masses of basalt which have broken into the basement conglomerate, and which may represent—as may also the Shap Granite—abortive attempts of the volcanic fires towards eating their way to the surface. Then in both areas we find the long unrepresented periods from Carboniferous to Glacial times, during which, after elevation at the close of or soon after the Carboniferous period, the mountain districts of Cumbria and Mona's Isle were respectively fretted by the denuding forces into their present form of hill and dale, under climates varying from semi-tropic warmth to glacial cold. As the cold of our last Glacial period, so called, reached its maximum, both districts were shrouded in ice-sheets, that of Cumbria self-born, that of Mona bearing down upon it most likely from a distance. Then followed a milder time and a submergence to such an extent that in all probability Cumbria was represented by but a group of islands and Mona disappeared entirely beneath the waves. As the land in both areas once more appeared, glacial conditions returned to a considerable extent, and floating ice laden with stones and boulders played its part in the cold drama, small bergs and floes being wafted first in one direction, then in another, as the currents changed with the varying amounts of elevated land. At length both the hilly areas of Cumbria and Mona stood up once more as of old, surrounded by a framework of low-lying land connecting the two districts, and allowing of the migration of fauna and flora from what by slight depression soon became the mainland, to the future independent Island of Man. Thus Mona is like a cast-off bud from Cumbria's group of rocky mountains."

SCOTLAND.—*Leadhills District Rocks.*—The excellent observations made by the officers of the Geological Survey of Scotland, under the direction of Professor Archibald Geikie, is adopted here. The geological structure of

* "Notes on the Geology of the Isle of Man." By the Rev. J. Clifton Ward, Ass. R.S.A., F.G.S., &c.

this district is best seen by taking a section from near Crawfordjohn across the Snar water, Leadhills, and the Green Lowther, to the valley of the Potrail water. In this section the Lower Silurian rocks traversed may be regarded as forming one great synclinal trough, since the lowest strata, which are seen to the north-west along the great boundary fault, rise again to the surface on the south-east side along the valley of the Potrail water. In reality, however, this synclinal trough is folded into several minor synclinal and anticlinal curves, so that the same series of beds is repeated more than once along the line of section. Two divisions of the Lower Silurian system are here represented—the Llandeilo and the Caradoc beds. The Llandeilo series consists of seven well-marked local groups of strata, which, for the sake of clearness, will be described separately in ascending order. They consist of the following divisions :—

CARADOC OR BALA BEDS.

	g. Black Shale Group.—Grey shales, with bands of fine-grained blue grauwacke and flinty mudstones, the most characteristic feature being the interpolation of numerous bands of dark anthracitic shales with graptolites—Estimated thickness	3,400 ft.
LLANDEILO BEDS.	*f. Lowther Group.*—Fine grey shales and finely-laminated felspathic grauwackes, with occasional grit beds—Estimated thickness	5,000 ft.
	e. Haggis Rock Group, consisting of coarse and fine grits and grauwackes, with associated bands of red and green flinty mudstone, conglomerate, and occasionally breccia. The most marked feature of the group is the occurrence of a persistent band of conglomerate containing pebbles of quartz rock, Lydian stone, and jasper, locally known as the "Haggis Rock"—Estimated thickness	
	d. Dalveen Group.—A series of fine blue and grey grauwackes and shales, having no marked characteristic to distinguish them from the other members of the Llandeilo series—Estimated thickness	
	c. Daer Group.—A series of hard blue and purplish grauwackes and grey shales—Thickness not ascertained.	
	b. Hartfell Shale Group.—Black and grey shales with graptolites—Thickness not ascertained.	
	a. Queensbury Grit Group.—Grey and purple gritty grauwacke, with occasional bands of pebbly grit—Thickness not ascertained.	

In the high ground round the villages of Wanlockhead and Leadhills, the Lower Silurian rocks are traversed by two systems of mineral veins, the one running north-west and south-east, the other west-north-west and east-south-east. These veins contain lead and other ores. Mineral veins have been observed in several other parts of the Silurian area, but not of a kind to offer any prospect of being ever worked for ores. These will be easily traced on the adjoining map of the Leadhills district, copied from the Geological Survey Map on the scale of one inch to the mile.

In the country marked by the Spango Granite, as well as the other Granitic areas, the Silurian strata strike at the Granite on one side, and reappear on the other, without deflection. The Granite, therefore, whether we regard it as metamorphic or intrusive, certainly occupies the area once filled by an equivalent mass of Silurian strata. Wherever a junction of the Granite and the Silurian rocks is seen, there appears to be a tolerably sharp line of demarcation between the two, no example of an actual passage from the foliated schist into the Granite having been met with in any part of the district. At the same time, it is to be noted that in many places they are locked into each other, as it were, by *numerous veins,* which proceed from the Granite, and run chiefly along the bedding planes of the altered rocks. Fragments of the stratified rocks are met with in the mass of the Granite, but

chiefly along its margin. These are usually angular and oblong, and vary in size from mere "galls" of a finger-length up to masses ten feet long or more.

In the area of the Spango Water and the Garepool Burn the Granite is a fine-grained mixture of pink orthoclase, with a little oligoclase, quartz, black mica, and hornblende. The quartz, which is second in abundance, is comparatively small in quantity, and the black mica is more plentiful than the hornblende. In the centre of each of these two areas the Granite becomes

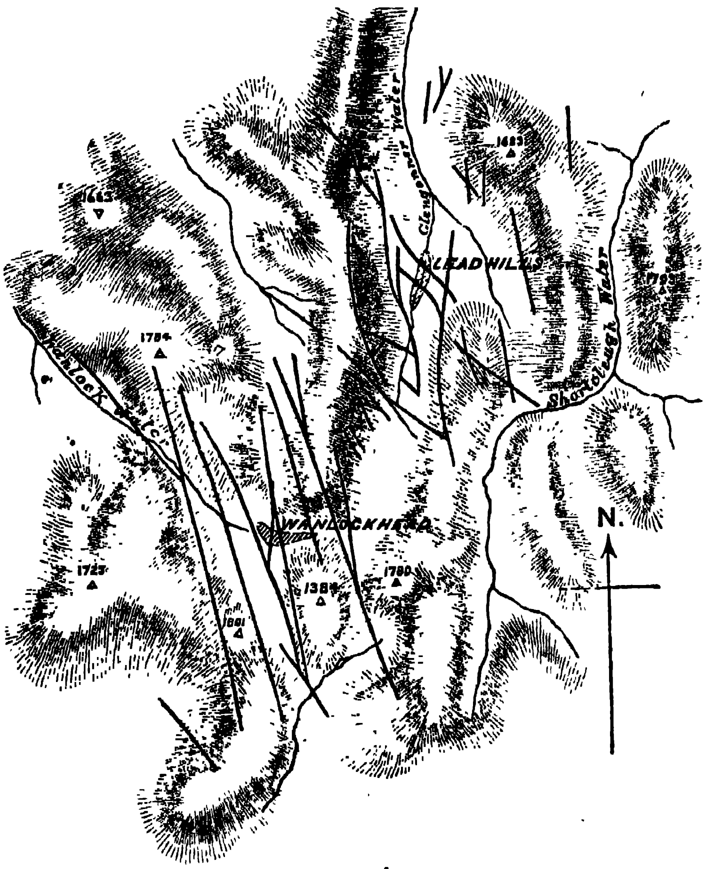


Fig. 34.—Leadhills and Wanlockhead District.

white in colour and coarser in texture, while the finest-grained varieties are those which occur in veins. In each district, also, the Granite weathers with comparative rapidity into a rusty-coloured sand. The waste is greatest towards the margin of the Granite, where the lower general level of that rock shows how much more readily it yields to disintegration than the more prominent altered rocks which rise up around it. A white coarser variety of Granite occurs at the Knipes, the Afton Water near Montraw, and at Cairnsmore. Round each of these areas the phenomena of metamorphism are well shown, the alteration of the mudstones being specially exhibited round the Garepool Granitic boss, and that of the schists round the Knipes; in the latter mass of Granite a *vein of antimony-glance* has been worked. It is worth

while observing, that while the Spango and Garepool Granites come to the surface chiefly in the Haggis Rock group, the Granite in the areas now referred to is entirely surrounded by the Lowther beds and a small part of the Black Shale group.

At Leadhills and Wanlockhead galena has long been worked extensively in the Silurian rocks. The direction of the lodes is, as will be seen on the accompanying portion of the Map of the Geological Survey, drawn to the scale of one mile to the inch—generally a little to the west of north—a few of the smaller lodes taking a north-west course. The heights of the hills are marked in feet, which will convey a correct idea of the physical character of the district.

The general character of the lodes may be gathered from the following description of a part of the Newglencrieff vein, laid open in December, 1868. The vein here hades to the east at 70° to 75°. Beginning at the last or "hanger" side, the order of the metals is as under:—

a. Grauwacke, part of the general Silurian rock or country.
b. Zinc blende, *black jack*, decomposing . . . . 1/3 inch.
c. *Vein stuff*, grauwacke ground up and mixed up with quartz . . 1½ inch.
d. Calc spar . . . . ½ inch to 1 inch.
e. *Galena*, sulphide of lead . . . . ½ inch.
f. *Vein stuff*, similar to *c*, quartzose and passing into pure quartz near the floor of the level . . . . 2 to 3 inches.
g. Blue grauwacke; joints veined with calcareous matter . . . . 3½ feet.
h. Hard, fine, compact quartz, with iron pyrites distributed in mass . . 7 inches.
k. Galena and barytes, alternating irregularly . . . . . . 8 inches.
l. Vein stuff, similar to *c* . . . . 4 inches.
m. *Grauwacke* (the *ledger side* of the vein) with *slikensides*.

The section is about 6 feet high. A string of the sulphide of zinc commences at roof of the level in *g*, and cuts through all the layers to *m*; *a*, *g*, and *m* are the country, and the other layers and the string are properly the vein. Farther westward a vein of sulphide of lead—*galena*—was found in the Silurian rocks to the south of New Cumnock, but it was not sufficiently remunerative to be continued.

Williams, in his "Natural History of the Mineral Kingdom," remarks of Leadhills: "They have frequently had remarkably rich lead ore in several veins, and one of them is said to have been up to 14 feet wide of solid ore (1789); and 4, 5, or 6 feet of solid ore have been at different times discovered."

The following passage, also quoted from this writer, is, on several accounts, especially deserving of notice: "The most beautiful masses of lead ore I ever beheld was a few years ago at Leadhills, in Scotland. I was then riding through Leadhills in haste, without the least intention of stopping, when a singular appearance of a fine bright yellow colour at some distance attracted my notice. I went up to it, and by some little breaks in some of the masses I saw it was a rich heap of fine lead ore, lying upon a shaft head just as it had been drawn out of the works, which ore I viewed and examined awhile with great pleasure and admiration. The masses of ore were pretty large, few of them being less than one hundred pounds weight, and many of them much more; and the outside of every one of these masses was of the *brightest and most beautiful yellow colour I ever beheld*, and inside of each of them was a bright blue, the common colour of lead ore. Upon nearer inspection, I found this glorious colour to be a rich *efflorescence* upon most of

the meshes; this yellow efflorescence was near an inch deep, of a fibrous, columnar, and striated texture, the columns shooting out regularly from the mass all around it, and all of them disposed perpendicularly and parallel to one another. In short, this was an exceedingly curious and a most beautiful natural production."

This is curious, as showing how small an amount of mineralogical knowledge the writer possessed, notwithstanding his great experience. The yellow crystallization described by him is well known in Derbyshire, and in the lead mines of Cornwall, as being the result of very recent changes. The beautiful "efflorescence," as Williams calls it, is no efflorescence at all. It is an accumulation of new crystals formed by the exposure of the galena.

A remarkable example of the very recent formation of a mineral ore of lead, of this description, was discovered a few years since by Mr. John Hunt, who for many years worked, with considerable profit, the old Roman mine at Pont-pean, in Normandy.

This gentleman leased from Mr. John Jope Rogers, of Penrose, near Helstone, the old Wheal Rose mine, near that town, to work above the adit and over the waste-heaps on the surface. This lease was afterwards extended to lower levels in the mine. For probably more than twenty or thirty years the workings of this mine had been suspended. One of the shallower levels, which had been for this period full of water, was now cleared out. On removing the water, it was found that the walls of the level were encrusted with masses of fine yellow crystals of phosphate of lead. This mineral is found in all the lead-producing districts. In Derbyshire it is called by the miner, *Linetts*.

Lead was discovered in the Limestone at Bathgate, where there was formerly a rich lead mine, yielding a considerable quantity of silver, and this mineral was found also near Calder.

THE ISLE OF ISLAY.—The mining field of the Isle of Islay, upon the west coast of Scotland, is remarkable for the great number of small veins or strings, some hundreds of which produced, and now contain, some small quantity of good lead ore, and yet certainly come to nothing at the depth of a few feet.

The Limestone in which the veins occur is so generally bare that the mineral veins are readily seen. There are a great many of these running north and south, and a great many east and west, which cross and intersect each other at nearly right angles, and there are many oblique or diagonal veins, which cross and intersect the others at all manner of acute and obtuse angles. There are also numerous *whin-stone dykes* of all sizes which cross and intersect each other and the mineral veins in all directions. Some of the whin-dykes are not a foot thick, others are 2, 4, or 6 feet thick, and several extend to from 8 to 12 feet, and some are thicker. Great numbers of these ribs of stone rise up in ridges above the surface of the ground, the Limestone being decomposed and washed away around them. These whin-dykes, Williams says, "are generally a species of that hard stone which naturalists call *basalts*, but that they are all mineral veins." He says: "I am very sensible that most of the miners will startle at this observation, and will be loth to own that they are mineral veins. However, I expect to

make it abundantly evident that they were originally the same sort of fissure, though filled afterwards in whole or in part with matter foreign from what is called mineral matter." The miners feel that Williams has to prove his hypothesis. He therefore relates that a late lessee of the mines of Islay had a rib of solid lead ore for some short time about three feet, and for a longer time about two feet wide, running parallel to one of those ribs of stone, in the same vein, and quite close to it, and deeper down in the same vein he had a considerable *wideness* of soft mineral soil, with some lead in it upon the other side of the same rib of stone. The phenomenon described here is often repeated with the Elvans of Cornwall and with the *Toadstone* of Derbyshire.

The number of superficial trials within a space not above ten miles over, is due, it appears, to the action of some Glasgow merchants who took a lease, and they employed the peasantry to dig and raise ore at so much per bing (8 cwt.). These people were allowed to work wherever they thought proper, and therefore every little string was followed down for two or three feet, and if not then productive it was abandoned.

The mineral veins of Islay occur in the Limestone, and are immediately connected with the basaltic rocks or whin-dykes. Williams describes a rib of solid lead ore, for a short distance about 3 feet and for a longer distance about 2 feet wide, running parallel to one of those ribs of basaltic stone and quite close to it, and deeper down in the same vein there was a considerable wideness of soft mineral soil with some lead ore in it upon the other side of the same rib of stone.

The principal way of procuring ore in Williams's time was by employing and encouraging the peasantry of the island to dig and raise ore at so much per bing. In consequence of the ore being seen on the surface, the country people laid all the veins open to-day in trenches or ditches where they found any ore. In some places they did not go down above 2 or 3 feet in the veins or strings, at most not more than 2 or 3 fathoms, when they generally came to more water than they could cast out with a dish.

LOSSIEMOUTH.—Williams says of this locality: "There is a singular stratum of stone near Lossiemouth, in the shire of Moray, of about 8 feet thick, which is compounded of several species of hard and fine stones of various beautiful colours. This stratum is a species of breccia or pudding stone, in the composition of which there is blended in some parts of it about an eighth part of good blue lead ore of the species called Potter's ore. This curious bed of stone lies in a horizontal position, and dips away towards the north, under the sea or Moray Firth, with an easy slope, and the lead is found in larger and smaller grains and flowers blended through the whole body and composition of the stone, in the same manner as the small masses of agate, white and coloured crystals, and other species of stone are found blended through the whole body of the stratum."

Although the remarks previously made embrace much that relates to the various conditions of the mineral veins, we must quote a few remarks on the phenomena observed in Scotland by Williams,* who gives some interesting examples of the opening of mineral veins, and mines in pro-

* "The Natural History of the Mineral Kingdom." By John Williams. Edinburgh: 1789.

gress, and he exposes some erroneous views which have prevailed: "I have seen a great number of superficial trials in such as carried some ore, but do not remember ever seeing a thorough trial made in any one of them. A little hole, 5 or 6 feet down, or a longitudinal slit along the vein, perhaps not so deep, generally ends the trial. How far this may be right I will not positively determine; however, it may be proper for me to give my own observations upon a point of so much importance to the public, as these veins are very common to be found in all countries where the superficies of the strata are seen; and in general I have observed that the greatest number of such veins as are roomy and capacious between the sides at a good depth—that is, from 10 to 20 fathoms down—are generally very straight, and close at the superficies of the strata; and besides such as I have seen in mining fields, I have examined great numbers of them in deep glens or gulphs, cut or scooped by rivulets in mountainous places, and upon the shores of the ocean in many parts of Britain, particularly round Caithness and other parts of the north of Scotland, round a good deal of the coast, and several arms or inlets of the sea in the Highlands of Scotland and part of Galloway; in all of which places the rocky cliffs are generally very high and clean, washed by the dashing of the waves; and it is astonishing what a prodigious number of the fine mineral veins are to be seen in many places upon those coasts, and many of them containing some ore and other good mineral symptoms, some of which I will point out hereafter. At present let it suffice to observe that the most of the veins which I have seen cut deep down by the water or otherwise, are narrow or close at the surface, and wider down below. At the same time it is also proper to observe, that it is very uncertain at what depth they begin to open. I have seen a great number of fine veins with their sides perfectly close above, so as to appear at the superficies of the strata no wider than a common joint, the sides of the vein, perhaps, not an inch asunder, which, nevertheless, would gradually open downwards, until the cavity or body of the vein between the sides, at 20 or 30 fathoms down, would be 6 or 8 feet wide, or more; and some of these veins, which are close above and wide below, begin to open soon, that is, 2 or 3 fathoms below the surface; others do not begin to open until they are 8 or 10 fathoms down; and, again, I have seen some which continue so close and straight for a great way down, that they would not be a foot wide at 20 fathoms below the surface, which, nevertheless, would open out to several feet wide at a greater depth.

"These remarks seem to favour straight or narrow veins, and, in my extensive observations, I do not remember seeing many such as are close or narrow at the surface which did not open below, if there was an opportunity of seeing them at a good depth.

"There may be several reasons given for this species of vein being narrow above and wide below, but these reasons will become obvious to the observing miner and the intelligent naturalist, when they come to read and consider the natural history of the phenomena of the strata in general."

After dealing fully with the general conditions of the more important veins, Williams directs attention to the clay veins, and makes some original

"The soft mineral soils are as various in quality and appearance as the hard. I will point out a few of them in which I will make no choice or arrangement, but will give them as they occur to my memory. The first I will take notice of is a white or whitish mineral soil or clay, sometimes fine, tenacious, and smooth, but often more friable and coarse to the touch, not unlike slaked lime mixed with small sand. This species of mineral soil is frequently a promising symptom of lead ore; but I will leave the discussion of this point until I come to examine the symptoms and appearances of mines or good mineral veins.

"2nd. Red fatty clay in veins, which indelibly stains the hands and clothes, is an indication of iron, concerning which I will say nothing just now, but that the better sort of iron ores are generally accompanied with red staining softness, by which they are easily distinguished; at the same time, it is proper to observe that some lead and copper veins contain a considerable quantity of iron, and consequently of a red or a brownish-red soft soil, and especially near the surface.

"3rd. Bluish and greenish mineral soils, light and friable, and also heavy and tenacious.

"4th. Yellowish, ash-coloured, and marbled soft soils or mineral clays, which are frequently not to be distinguished from surface clays of the same colours but by the skilful miner.

"5th. Black and blackish-brown soft soils, commonly light and friable, though there are some of them more tough and weighty.

"6th. The most remarkable and distinguished of all the soft mineral soils, and frequently the most promising, is of a brown colour, and of a lax and friable texture, often resembling rappee and other snuff in colour and appearance, being sometimes blackish, but generally brown, in all the degrees and shades of that colour. . . . . These soft lax soils are called *mothers* by the Scotch miners, and where discovered in a vein they are generally reckoned a good omen for lead and copper."

STRONTIAN.—All the rocks in the mining field of Strontian are a grey Granite. Several veins in this district were opened by the York Building Company, and a considerable quantity of lead was raised by them. The principal vein worked was regarded as having been the strongest mineral vein in Britain. The York Building Company found a large body of ore at first cutting quite up to day, which they worked out *open-cast*, that is, these works were cut up quite open to the surface, like a large longitudinal trench or gulf, the vein being exceedingly wide, and they did not mine it under cover at all.

"The lead ore of Strontian is of the species called *Potter's ore*, on account of its being a pure galena, especially useful to the potters" (*Williams*, 1789).

The geologists engaged on the Geological Survey of Scotland give the following list of minerals and metallic ores which occur in the Leadhills and other districts of Scotland.

COPPER.—Copper ore has been found at Currie, on the Lothians, and at Kissern, in the Highlands of Ross-shire, and trials for working these deposits have been made in the Limestone quarries. The copper raised was of the best quality. Copper pyrites is an occasional constituent of the Leadhills

and Wanlockhead mineral veins, but it has been worked but rarely. In the Shetland Isles, at Sandlodge, copper ore has been raised in some quantity. In 1880, 1,813 tons of ore produced 92 tons 10 cwt. of copper, and in 1881, 232 tons. In the former year 396 tons of iron ochre were obtained from the ochre pits, and in the latter year 100 tons.

ANTIMONY.—A rich vein of antimonite, or sulphide of antimony, was formerly worked on part of the Knipes Granite at a place called Hare Hill, to the south-east of New Cumnock. The workings have been discontinued, but many tons of the ore are still to be found near the mouth of the old mine. Small quantities of antimony are also met with in the mineral veins of the Leadhills tract.

MANGANESE.—On the old Sanquhar road, about a mile north-east from Wardlaw Hill, a vein of barytes occurs, containing small quantities of finely-mammillated pyrolusite. The same Manganese ore is met with also in the veins of Leadhills and Wanlockhead.

ZINC.—"Black Jack," or sulphide of zinc, is a common constituent with the galena veins, and occurs sometimes in considerable quantity.

SILVER.—The galena of Wanlockhead is sufficiently argentiferous to allow of the extraction of the silver with profit.

GOLD.—For more than three centuries gold has been collected in small quantities from the alluvia of the streams in the Leadhills and Wanlockhead district, and also in Sutherlandshire.

BARYTES.—The existence of a barytes vein, which is in many places 15 feet thick, may be traced from near the head of Gass Water for two miles in a north-westerly direction as far as Knockbreck. Another barytes vein, about 3 feet thick, sometimes containing hæmatite iron ore, occurs on the flank of Auchensaugh Hill, lying to the east of the Douglas coal-field.

IRELAND (*Wicklow*).—The natural division of the county of Wicklow is, according to Mr. W. W. Smyth, into an elevated mountain tract of Granite on the west, and a region mostly composed of Clay-Slate on the east. The boundary-line between the Granite and Slate regions runs from north-north-east to south-south-west, and within a small width along its western side, veins of lead ore have been discovered at intervals for a distance of about thirty miles.

The Granitic veins, varying from an inch to several feet in width, exhibit a general tendency to follow very nearly the meridian line. A riband of quartz frequently accompanies them, sometimes at the side and sometimes in the middle of the vein. The important mining operations which have been from time to time carried on here will form the subject of further consideration.

In the cliffs on the side of Comaderry Mountains, in which quartz greatly predominates, copper pyrites and galena are interspersed. Mr. Weaver relates that a lump of sulphide of lead, weighing about a ton, was found near the surface where the veins entered the mica Slate. Among the Granite precipices of Glendalough, about eighty fathoms west of old Luganure vein, a north and south lode was discovered. This lode carried a rib of decomposed Granite on its hanging side, and fluor-spar of a green tint. The mines of Ovoca have for many years yielded at the rate of 100,000 tons of pyrites annually.

GOLD.—In 1795, lumps of gold were picked up in a valley on the flanks of Croghan Kinshela. It was found that the gold occurred disseminated in an irregular bed of clay, sand, and rounded fragments of rocks, with large masses of magnetic iron ore. The speculations on this remarkable detrital deposit have been many, and more frequently led by imagination than regulated by fact. No opinion of any value can be at present formed on the origin of these auriferous deposits, but the fact of the occurrence of gold in the pyrites of Wicklow appears to point to a source from which it might have been derived.

COPPER.—The mines of copper are in three well-marked groups: the first group in County Wicklow, occupying the valley of the Ovoca; the second in County Waterford, around Knockmahon; and the third situated in the southern portions of Cork and Kerry.

Mr. Weaver, who was for many years the manager of the Wicklow mines, has described them most accurately, and from his writings many of the following particulars are gathered. The Clay-Slate district, which corresponds with the Killas of Cornwall, occupies a narrow space not more than ten miles long, from Croghan Kinshela on the south, to West Acton on the north. The metallic minerals are extensively diffused in thin layers, in well-defined veins, and in massive deposits. At various depths in the Clay-Slate occur beds of "soft ground," which are decomposed slates, varying much in colour. These beds abound in particles of iron pyrites, arsenical pyrites, and copper pyrites, and occasionally the sulphide of that metal. Decomposition in this soft ground has gone on to a considerable extent, and the result has been the formation of alum, copperas, sulphate of iron, and sulphate of copper. The drainage waters from these beds is strongly impregnated with copper, which is separated by being run into pits in which scrap iron has been placed, and thus a large quantity of precipitated copper is obtained.

Each bed of soft ground contains one or more layers of copper pyrites or iron pyrites varying in thickness, but sometimes acquiring a breadth of several fathoms. Five of such beds are met with—one in Connoree, two in old Cronebane, and one in the new mine, and one in Tigroney. That in Connoree contains a bed of ore about 4 feet thick, consisting of an intermixture of galena, grey copper ore, blende, and copper and iron pyrites, sometimes combined with sulphur in much purity, at other times containing arsenic. At Cronebane the same compound is found in the upper mine, but in the southern bed the iron pyrites has been very extensively worked, and grey copper ore has been obtained to the extent of several thousand tons, passing in depth into copper pyrites (yellow copper ore). The third bed in this mine has been the most valuable, the bed of solid ore varying from 1 to 3 fathoms in breadth without any intermixture, the more productive parts of the bed giving from 10 to 15 tons of merchantable ore per cubic fathom, the average produce being from 5 to 7 per cent. for copper. Tigroney has yielded large quantities of iron pyrites, the beds, which are in a firm condition, varying from a few feet to some fathoms in thickness. In the flinty slate are found several veins of quartz, with rich copper pyrites, and purple copper ore producing from 10 to 12 per cent. of metal. These

veins range with the Slate, and where they run together they sometimes form a body 12 feet wide, with 4 or 5 feet of solid ore; but these veins are seldom more than 30 fathoms in length. The Slate rock is traversed by numerous smaller veins. The mines of Connoree, Cronebane, and Tigroney are on the north bank of the Ovoca River. On the southern side are the celebrated mines of Ballymurtagh and Ballygahan. These mines are in a precisely similar strata, and are in all conditions like those already described.

In 1799 the mines of Cronebane yielded 7,533 tons of copper ore, containing 9 per cent. of copper. In the twelve years ending 1811 the produce was 1,934⅝ tons of copper pyrites, giving 5 per cent. of metal. In 1826 the copper ore raised at Cronebane was sold at Swansea for £12,354 14s., and that from Ballymurtagh was sold for £3,373. The Ballymurtagh mine was worked by the Hibernian Mining Company on a single vein containing copper pyrites. The vein at 80 fathoms gave 4 tons of dressed ore per fathom of 5½ per cent. produce. The following returns of copper ore sold at Swansea for three different years are given by Dr. Robert Kane*:—

	1836.—Tons.	1840.—Tons.	1843.—Tons.
Ballymurtagh	4,659	3,274	1,385
Connoree	2,158	3,017	654
Cronebane and Tigroney	4,691	158	1,160
Ballygahan	305	198	28

It must, however, be remembered that this does not represent the total produce of these mines. The quantity of ore sold at Swansea—from several causes—diminished; much was smelted in the neighbourhood of Liverpool; the poorer ores of Wicklow were sold to large chemical works, and the sulphur was extracted, the copper saved, and both silver and gold obtained from the residuary matter after the first processes had been completed.

Copper ore occurs in some of the Slates of the Upper Old Red Sandstone towards Kenmare Bay. It is nearly always grey copper ore that is found in the Slates, which decomposing, stains the rocks with the green carbonate of copper. Lead ore was worked for some time to the south-west of Cahirmore.

Specular iron is found in most of the quartz veins associated with the copper, especially in two veins of quartz on Bear Island, one about half a mile east of Ardnakinna Point, and the other west of Carrigbreedia.

Both copper ores and lead are found in the Limestone and the Old Red Sandstone rocks of the Kenmare Valley. One deposit, called Trinity lode, strikes with the beds of the Old Red Sandstone at Greenlane, about 300 yards south of the basalt boundary of the Carboniferous Shales. Copper pyrites appears in the Slates at Cromwell's Fort. Lead ore occurs in the grey Limestone close to the Roman Catholic chapel at Kenmare, but this is probably only a bed.

The Shanagarry lode contained argentiferous galena, some iron pyrites, and blende. It is near Shanagarry Castle, north of Cleady Bridge. The Ardtully copper mine is worked on a true lode, which strikes in a west-north-west direction across the Limestones, which dip about south 10°, east at 80°, the lode itself inclining south. It was worked to the depth of 60 fathoms, and produced grey copper ore, copper pyrites, and purple ore. The lode under-

* "The Industrial Resources of Ireland." By Robert Kane, M.D., F.R.S. 1845.

lies south 2 feet in 6 for the first 40 fathoms, and then becomes vertical. Copper in limited quantities has been found at Derreenacahill and Furtane Lower. Traces of carbonate of copper have been noticed near Caher. The green carbonate of copper, however, occurs plentifully distributed between the purple and yellow slates of the Old Red and Yellow Sandstones in the south of Ireland.

Some years since a large quantity of copper ore was raised on the shore near the Devil's Island, from the Limestones of Muckroos Demesne. The lode was subject to much disturbance, and the mineral was consequently very irregularly distributed. By some this was thought to be a bed, but it was no doubt a true lode.

Waterford District.—Within a range of three miles from Bonmahon a number of lodes of lead and copper are observable in the cliffs, some of fair width, but many very small. The direction of the principal lodes is about 20° south of east, and the usual dip is towards the north, but there are many considerable deviations. The most productive lodes occur in the Clay-Slate, but the lodes sometimes pass on into hornstone, in which several *ores of cobalt* have been found, but not in large quantity. The lead veins, which have been rarely worked, are usually charged with galena and calc-spar. The copper veins consist of quartz, native copper, sulphide of copper, and grey copper ore, and the black oxide of copper, sulphide of zinc, carbonate of iron, and sulphate of barytes are also occasionally found.

Captain John Petherick communicated to Dr. R. Kane many important particulars respecting Knockmahon mines, which, as manager, he had ample opportunities of gathering.* From this letter a few especially interesting notes are gathered. The Slate rock in which the mineral occurs is of a soft character, and immediately in contact with the productive part of the lode is softened or partially decomposed. The veins are composed of compact hard quartz, which is the matrix of the lode, intermixed with angular fragments of Slate. The principal vein varies in width from 6 inches to upwards of 30 feet, but the average size may be regarded as about 12 feet, numerous smaller veins occurring on either side. The mines of this district, which includes Knockmahon, Kilduane, Bonmahon, and Balinasisla, are worked by the Mining Company of Ireland. The mining ground leased to this company extends about 4 miles along the coast and nearly 3 miles inland. The average percentage produce of those mines is 9½ to 10 per cent. The main lode—or rather a portion of the large vein—is composed of a conglomerate of pebbles of quartz, and copper ore in soft Clay-Slate. Sometimes the fragments are angular, but frequently they occur in a rounded state, and occasionally the copper is disseminated in small particles throughout the mass. This may be regarded as good evidence of the filling in of the lode from the surface.

The aggregate produce of these mines in the years given was—

		£
1836	3,588 tons	33,166 value.
1840	7,875 „	63,087 „
1843	9,101 „	62,950 „

* "Industrial Resources of Ireland." By Robert Kane, M.D., F.R.S. Second edition. 1845.

Near the Blackwater River, in Tondin Demesne, is a thin-bedded and flaggy Limestone, containing chert bands dipping to the south at 60°, being part of the lower Limestone Shale. In this rock, near Camphire House, nearly a half-century since, a vein of lead and silver was worked.

The Clay-Slate formations in the counties of Cork and Kerry give certain mineral indications, but the hopes encouraged by these have rarely been fulfilled, and considerable loss has followed nearly all the adventures.

Allihies or *Berehaven* mine was discovered about eighty-two years since in the land of Allihies. In the space of three or four miles there are several veins, most of which run east and west, and dip towards the north. Two veins were found to be very productive, and the works have been mainly carried out on these. One is known as the *Mountain* mine, which is situated about 450 feet above the sea-level, and is a large east and west lode. The other is *Caminche*, which runs north-east. There were, when the mine was about to be abandoned in 1881, five different veins giving names to as many mines, called respectively, Keallouge mine, Mountain mine, Caminche mine, Coom mine, Dooneen mine.

The principal workings in the Mountain mine are about 700 feet in length, and the mine has been worked to the depth of 249 fathoms below the adit. The lode is in one place 60 feet wide, but in other places it diminishes to 3 or 4 feet. At a short distance from the copper veins is a vein of lead, but it has not been worked. The Caminche mine is worked for about 570 feet in length and 130 fathoms in depth below the adit. The Keallogue mine is worked to the depth of 240 fathoms. The vein runs north-east and dips south-east, the width of it being from 1 foot to 12 feet.

In the Limestones of this district near the townland of Cloghatrida, which lies to the west of Stoneville, there was a lode containing copper, lead, blende, and iron pyrites. The lode ran nearly east and west, and underlying to the north at 70°. The quantity of copper obtained never paid for working. In the townland of Ballingarrane a lode was discovered bearing north 45° east, from which a few tons of copper were obtained and also a little calamine.

A short distance from Bantry, at Holyhill, a vein of copper has been opened; but it was not found profitable, and it has been abandoned.

At Ardtully, near Kenmare, a copper mine has been worked by the Kenmare Mining Association. This vein consists of quartz and calc-spar, containing some copper, and is about 5 feet wide.

At Ross Island, in the Lake of Killarney, is a metallic lode passing through it, and running parallel to that of Mucruss. The lode dips under the lake at an angle of 30°. About 200 tons were raised in each month while this mine was at work. The poorest ore sold at £14 per ton and the richest at £40. The total value of the copper ore raised in the four years during which this mine was in operation was £80,000.

The mountains in the north of Tipperary, in which is the gorge of Killaloe, contain many lodes of lead and copper; but these have not been found profitable when worked, and they have consequently been abandoned. At the junction of the Clay-Slate and the Old Red Sandstone the district known as *Silver Mines* exists. A split between the Limestone and Clay-Slate, several fathoms wide at the surface and about 25 fathoms deep, was

filled in with a decomposing clay, with lumps of the adjoining rocks cemented by the sulphide of lead, copper, zinc, and iron. The lead was separated, and from the large quantity of silver which it contained the name of Silver Mines was given to the spot.

Lackamore mines are in the valley of the Newport River. The lode which was worked consisted of carbonate of lime and iron, with bunches of rich copper ore. When Mr. Weaver wrote in 1812, the workings had extended to the length of 120 fathoms, and to the depth of 30 fathoms. When Dr. Kane published his "Industrial Resources" in 1845, he says two hundred men were then employed, "and there were sold in Swansea from this mine, in 1840, 111 tons of ore, which produced £1,153 7s., and in 1843 200 tons of ore, which realised £2,386 18s."

Copper ores have also been found in the Slate district north of Dublin; at Lough Shinny, near Rush; on the coast at Salterstown, in Louth; at Brownstown, in Meath; at Tyrone, a few miles from Dungannon. At this latter place large masses of the grey sulphide of copper have been found in a vein of conglomerate resting on the Old Red Sandstone, but none of the attempts made to work at this spot proved commercially profitable.

Lead ore has been found in many parts of Ireland, and is distributed through a greater variety of rocks than copper ore.

Along the eastern boundary of the Granite district of Dublin and Wicklow a number of small veins containing lead ore are found; they cross in an oblique direction the junction of the Granite and mica Slate. Mineral lodes have been worked for lead at Dalkey, Killiney, or Ballycorus, at Powerscourt, Djoun, Lough Bray, Lough Dan, Glenasane, Glendalough, Glenmalur, and Shillelagh. With two or three exceptions, none of these trials have led to any permanent mining operations.

Through the Granite mountains which enclose the lake and ruins of the Seven Churches numerous veins of quartz exist, and in these are found ores of lead and occasionally of copper.

At Glenasane a vein of quartz 6 feet wide passes nearly from east to west. It contains galena, blende, and iron pyrites.

The vein of Luganure runs altogether in Granite. It crosses the Comaderry Mountain, and has been traced for near 900 fathoms, and its ascertained depth is 180 fathoms, and is almost always about 5 feet wide. Mr. Weaver states that this vein yielded from 3 to 4½ tons of galena to the cubic fathom, giving generally 70 per cent. of lead.

The old Luganure mine, and a neighbouring one, the Hero, have ceased to yield any produce; but the mine of Ripplagh, on the eastern side of the glen, and one on the western side, at the base of the Luganure Mountain, are still termed the *Luganure* mines. In 1842 these mines gave 675 tons; in 1843, 547½ tons; and in 1880 they were yielding to the Mining Company of Ireland 897 tons 19 cwt., containing 3,360 ounces of silver; and in 1881 they gave 822 tons of lead, yielding 4,932 ounces of silver.

The Ballycorus lead mine is worked on two veins, which run nearly parallel, and cross the junction of the Granite and mica Slate. The workings on these veins generally follow the course of the lode, they sometimes diverge, and occasionally coalesce. Whenever this is the case valuable bunches of

ore are found. The Mining Company of Ireland, in 1845, discovered a new vein which contained a lode of native silver. The discoveries made have not, however, on the whole, been found to be profitable.

At *Glenmalure*, on the northern side, a powerful metalliferous vein presents itself. It has been traced about 400 fathoms. Mr. Griffith describes it as being on the average 15 feet thick, and curiously divided into five parts. There are 3 feet of a soft slaty substance, with a layer of talc; then a vein of quartz, from 1 to 3 feet thick—in this lead ore is usually found; then again 2 feet of quartz, in which the largest quantity of lead ore is found; and then another layer of talcose matter.

On the opposite side of Glenmalure several lead veins have been found. They have not, however, been found to be of much value.

At *Caime*, in Wexford, in the Clay-Slate a good quartz vein has been found bearing galena, carbonate of lead, sulphide of zinc, with pyrites. Copper ore was sold from this mine, and the Mining Company of Ireland obtained for a few years from 200 to 500 tons of lead ore, giving 75 per cent. for metal.

In Louth, Down, and Armagh, lead mines have been opened. At *Armagh*, in Derrynoor, one mine gave for several years about 200 tons of dressed lead ore per annum. At Keady, in the same county, a vein of lead was discovered and worked for some time. Of this mine Sir Charles Coote, in his "Survey of Armagh," says: "This mine is on the estate of the college of Dublin. The lands are held by the Earl of Farnham. The late Earl expended large sums in sinking and working, but made no profit by it. It is rather wonderful, and, indeed, proves the value of these mines, that he was not a considerable loser, as he had no active partner to superintend works under ground which he never saw himself. The vein is so rich and abundant it would be well worth the attention of the monied undertaker." There is no intimation that this mine has ever been reopened.

At *Ardenore*, in Waterford, and at Ardtully, near Kenmare, lead has been found, but no profitable workings have been carried forward. In the creek of Ringabella a lode of lead has been found in the Carboniferous Slate. Lead has also been discovered in Connemara in the Granite and mica Slate, and in the same rocks in Donegal. At Kildrum the Mining Company of Ireland opened a mine for lead, but it did not prove a profitable adventure. The Limestone formations of central Ireland give evidence of the existence of lead ore, but the mines have rarely proved productive owing mainly to the abundance of water, rendering drainage difficult and expensive.

At Clontarf, near Dublin, a lode of lead ore and blende was discovered and for some time worked. It was on the seashore, and eventually a high spring tide flooded the mine, and it was abandoned. Numerous veins of galena are known to exist in the neighbourhood of Dublin, but none of them have been found to be continuous to any depth.

At Beaupare and Athboy, in Meath county, and in Kilkenny, lead ore very rich in silver has been found, but at Floodhall only has any profitable working been carried on. The *Milltown* lead mine, in the barony of Tully, in the county of Clare, is probably one of the oldest lead mines in Ireland. In 1836 it was worked by Messrs. Anthony Colpoys and George O'Callaghan,

under the management of the late Mr. John Taylor. The ancient workings were found to be very extensive, but the modern workings were abandoned in 1838, after raising forty tons of ore only, which yielded 75 per cent. of lead and gave 37 ounces of silver to the ton.

Kilbricken mine, in the barony of Bunratty and the parish of Dura, two and a half miles from Quin, and six miles from Ennis, was opened in 1833. About 25 tons of lead were raised, which gave 76 per cent. for lead and 120 ounces of silver to the ton. The water from the surrounding bogs was an obstacle to progress. In 1837 a steam-engine was erected.

Ballyhickey mine, in the parish of Clooney and the barony of Bunratty, is the richest lead mine which has been discovered in the county of Clare. Operations were commenced on this mine in 1834, and up to 1845 about 2,500 tons of lead ore had been shipped from Clare to the Dee. "The three deposits of ore above mentioned" (we quote Mr. John Taylor) "occur in large veins of calcareous spar, which traverse the Limestone rock of this country. They differ from any hitherto observed in the mining districts of England and Wales, and indeed upon the continent of Europe. The veins of spar are of immense width, in places from 20 to 30 feet, and they run generally a little to the north of east and south of west.

"The quantities of ore found at Milltown and at Kilbricken are so small, and the masses of spar so large, that it is not easy to trace the intersections of veins or branches at the points of deposit as distinctly as at Ballyhickey. There the bunch of ore—the richest probably that was ever seen, taking the number of solid fathoms of ground broken into account and the tons of ore raised—occurs at the intersection of two veins.

"The main vein runs north-east and south-west, and its tributary falls in an angle of 45°. At this point the mass of ore was from 16 to 20 feet wide in places almost pure; in others raised with sulphate of copper and zinc. The total length of the rich branch was about 40 feet, and it is still orey at the depth of 11 fathoms; how deep it may be worth pursuing is a question yet to be solved."

The lead ores of Ireland are all argentiferous, but they vary considerably in the quantity of silver which they contain. The average produce of silver extracted from the lead ores worked by the Mining Company of Ireland has been about 7½ ounces to the ton of lead.

The following gives the result of several assays of lead ore for silver published by Dr. R. Kane, whose chemical accuracy is undoubted:—

From Luganure, Wicklow	3 ounces
" Caime, Wexford	12 "
" Ballyhickey, Clare	15 "
" Kilbricken, Clare	120 "
" Tollyratty, Down	10 "

CHAPTER II.

MECHANICS OF MINERAL LODES, FAULTS, CROSS COURSES, ETC.

PREVIOUSLY to entering on the subject which it is purposed to place before the reader in the clearest possible light, it is necessary that he should be familiar with the correct meaning of the terms employed, whether they are spoken by the working miner—using a provincial term—or by the educated man who employs terms familiar to him—and probably of archaic origin, being forms used when the earliest attempts were made in this country to extend subterranean explorations. Some space will therefore be devoted to an examination of the terms which will be often met with in our mining districts.

Mine.—A subterranean working in search of some mineral.

"A mine is formed by the penetration of the surface, without exposure of the works to the light of day, by means of pits, shafts, levels, or tunnels. . . . . It is inaccurate to say that a mine is unopened. The mine is not the substance, it is only the mode of getting the substance. A vein or stratum may be unopened, but there can be no *mine* if there is no opening."*

In the districts where ironstone is raised with the coal, MINE is very commonly applied to the substance—so much *mine*—meaning iron ore—is to be put into the blast furnace. Several writers use the terms *vein* and *lode* as being synonymous, and probably these words have been so frequently used to express similar conditions, though not *the same*, that they may really now be regarded as synonyms. *A vein* was originally applied to appearances in the rocks which bore some resemblance to the blood-vessels or veins of the animal body. These are usually due to *injected* matter, and they vary in their names according to the substances of which they are composed, in the following order:—

Granite Veins in Granite.—These are evidently due to the injection into pasty Granite of Granitic matter in a fluid or semi-fluid state. These are commonly spoken of as being *contemporaneous*, but the vein must assuredly be newer than the Granite into which it is intruded.

Granite Veins in Slate.—These are really of the same general character as the preceding, but they have been formed by the action of heat and mechanical force upon the imperfectly formed Granite mass, the softer portion, under enormous pressure, being intruded into the still plastic clay, slowly hardening into Slate. These not unfrequently present a curiously-branched character.

Elvan Courses, or Dykes.—They are almost always of a Granitic character, only much finer than the adjoining Granite.

* "Laws of Mines and Minerals." By William Bainbridge.

Felspar Veins are nearly of the same character—but more or less felspathic. At the Logan rock they are compact felspar, and of a reddish colour.

Mica Veins are generally small, and consist of two layers of mica in thin plates. These are to be seen at St. Michael's Mount, and in the Granite near St. Austell.

Schorl Veins.—These are found both in the Granite and Slate, and are seldom more than an inch wide, though in the Crown rock at Botallack mine they are found nearly a foot wide. These are generally short, and they scarcely fulfil the conditions required by the term *vein.* They are rather concretionary masses of tourmaline, or, as the miners call them, "*floors of cockle.*" In Zennor parish, Schorl rock traverses the Granite veins which appear on that coast.

Quartz Veins are found intersecting the Granite and Slate, and Greenstone and Limestone. They are of two kinds, one kind being very irregular in size, direction, and inclination; the other, filling in fissures, partakes of the nature of a *fissure lode.*

Steatite Veins are also found in the Serpentine rocks, and they occur in some places in considerable masses. Agate, jasper, opal, and fluor-spar are found in veins in the so-called igneous rocks, and in the deposit beds of Slate and Sandstone. *Veins of Asbestos* occur in the Serpentine rock of the Lizard, and sometimes in the Greenstone and Serpentine of Clicker Tor, near Liskeard.

All these veins occur—with the exception of schorl veins—at or near the junction of dissimilar rocks. They are never metalliferous, although sometimes, especially in Elvans, strings of stanniferous matter are found running parallel to the vein.

Very different opinions are expressed with regard to the ages of these veins respectively; but this question remains still a very unsettled one, and therefore cannot be made in this volume a subject of discussion.

*True Lodes, or Mineral Veins.**—These are to be especially distinguished from the veins already mentioned. Some writers have been induced to use the term *vein* without sufficiently indicating the meaning which they desire the word to convey. "The name *lode* is given by the miners to every vein which appears likely to produce metallic substances" (*Carne*). It is thought, after the most serious consideration, it will be wise to use the term *vein* according to the definition already given, and apply the term *lode* to fissures or cracks filled in with metallic ore, and to restrict the distinctive term of *mineral vein* to all metal-bearing fissures.

It is not a little curious to trace the origin of the terms applied to the various conditions prevailing in the rocks which are brought under the eye of the miner, as in the earlier time especially, in his rude way, he pursued his exploration. Advancing from the working, illiterate miner, who is always much of a theorist, we find educated men, who usually draw their conclusions from observed facts, discussing in a strange way the origin of the terms used to express the channels in the rocks in which we usually find the metalliferous minerals. Mr. William Phillips, the mineralogist, in 1800, is anxious to inform us that he was "at some pains to discover the original meaning of the term" *Lode*, or *Load.*

* These are called by Mr. J. Carne *true veins*, in his paper "On the Relative Age of the Veins of Cornwall," in the "Transactions of the Royal Geological Society of Cornwall," vol. ii., 1814.

He refers, he tells us, to Borlase, and he finds the "learned doctor" writing, "From the fissures let us proceed to that which they contain; *whatever fills them* we call a *lead*," making a distinction between the *fissure*, or *vein*, and the substance it contains. Borlase again says, "Where the *load* is barren it may serve to *lead* to that which is rich;" and in a note he concludes "the term *lode* to be an old Anglo-Saxon word meaning *lead*, thus *load*stone meaning *leading* stone, and refers to Junius." Phillips says: "I am induced to believe the term *lode*, though thus spelt by Borlase and Pryce, originally meant the burthen or *load* of the metalliferous vein. Carew, whose 'Survey' was published almost a century ago, not only so spells it, but, in speaking of the effects of the flood on the rocks of the county, says it carried away so much of the '*load* as was contained therein.' Besides, it is to be noticed that the north and south veins *which are not metalliferous* are uniformly called *courses*, making a clear technical distinction between unproductive and metalliferous veins."

The term *vein* was evidently applied to the cracks or fissures found in the Earth's surface through a conceit, of very ancient date, that they bore some analogy to the venous blood-vessels of animals. Indeed, within the last half-century a mechanical genius, of considerable and well-earned celebrity, told the author that he believed the earth to be a living animal, and the cracks and lodes so many venous and arterial vessels through which the life of the animal circulated. The application of the term *lode*, or *load*, to these when filled in with metalliferous matter, is exceedingly uncertain. The Anglo-Saxons had scarcely any connection with the mines, certainly not sufficient to warrant the idea that they gave a name to the fissures in which the metallic minerals were accumulated. Phillips is wrong in supposing that the term *lode* was applied only to the east and west veins. The lodes of St. Just, which are not east and west, and the lead ore veins near the Tamar, running north and south, are still called lodes. The fissures running at right angles to the productive lodes are certainly often called *cross courses*. But there is a distinction which should be always borne in mind between a mineral vein and a cross course. A mineral vein is the result of a mechanical disturbance acting in one direction, and a cross course is due to a disturbance acting at a different period at right angles, or nearly so, to the primary movement.

It will prove convenient to explain here a term very commonly used by miners in nearly all parts of the United Kingdom.

The Country.—This name is given to the rocks through which the miner pursues his search for mineral treasures. All *the rocks* in a metalliferous district are termed "the country." Phillips says: "If a miner be driving an adit north and south, or in any direction other than that of the lode, he says he is 'driving through the country.'" This is not exact. When a miner follows the lode in its general direction he always speaks of "working on the lode," and whether the mineral vein runs east or west, or north and south, the rocks on either side of it are known as the *country*.

Mineral veins are sometimes named from the direction which the fissure takes in the rocks. Dr. Berger observes that the French used to call veins pointing east-south-east and west-north-west "*filons du matin*." The Cornish

miners, Mr. Carne says, have carried this idea much farther. They call veins whose direction is due east and west *six o'clock veins*; and north and south veins *twelve o'clock veins*; the veins, therefore, which run fifteen degrees north of east and south of west are *five o'clock veins*, and those which run fifteen degrees north of east and south of west are three o'clock veins, and those which point south-east and north-west are nine o'clock veins. It appears that similar modes of describing the direction of veins obtained in Freyburg. There is, therefore, but little doubt that we adopted these terms from the German miner. In the north of England a similar custom at one time generally prevailed. In other cases the names are adopted from the conditions which prevail in the fissures as they penetrate the rocks, or they are described according to their contents. These names vary considerably in different districts, but in the following definition of the miner's terms an attempt is made to give their generally received meaning.

The mineral veins in the Limestone of Derbyshire are known by several names, derived principally from their direction, and their dip or underlie.

Rake Veins are seldom truly vertical; they almost always sensibly incline, or, as it is generally termed, *Hade*. Sometimes the vein dips at the same angle throughout, but in some it changes as we descend. A vein first hades south, then north, then south again; this arises from the character of the rock through which the vein passes. A crack taking place through a series of beds—where each bed differs in its physical condition—will naturally produce a fissure, altering its *hade* or dip in passing through each one of the beds, as shown in the annexed woodcut, Fig. 35.

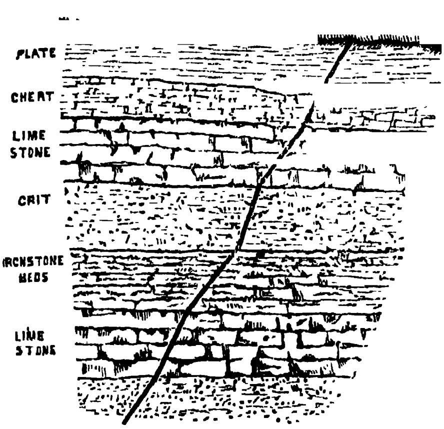


Fig. 35.—A Fissure Vein.

The Rake Veins are said by Farey to be the most numerous in Derbyshire. They generally preserve a pretty straight course on the surface, and they often run parallel with each other, having others crossing them almost at right angles.

The vein underneath a *Toadstone* bed is seldom of the same width below it as it is above it, and the parts do not exactly correspond. The vein is then said to have been *squinted*, or thrown aside. The rake veins of the miners are vertical mineral fissures. Williams, in his "Mineral Kingdom," says: "They are longitudinal gashes, rents, or openings in the rock or strata, commonly running in straight lines. This gash or fissure cuts all the strata and rock quite through, from the surface as far down towards the centre as that vein dips, which is generally out of our reach, and as far forward in the line of bearing as that vein reaches. . . . The rock upon both sides of the vein are called by the miners the *hanging side* and the *ledger side*; some miners call them the *hanging side* and the *hading side*, and the longitudinal line which the fissure points to, is called the *bearing of the vein*.

"Of these perpendicular fissures or rake veins there are two species. The

origin of one of these is a crack or rent and a slip of the strata, and the other is a gash or chasm in the rock without a slip; the sides of the gash are separated and opened asunder, but the edges of the strata upon both sides of the fracture continue opposite to one another, so that there is no slip."

There are numerous varieties of the rake vein which are mainly due to the inclination from the vertical. These veins vary with the declivity of the strata, and when parallel and oblique veins have a considerable *hade*, or slope, they are called irregular veins. These veins are generally very troublesome to work on account of their *hade* and of its irregularity, and the frequency with which they vary their slope. "Besides the frequent variation of the slope or hade of these veins, the two sides, or *hanger* and *ledger*, of these veins are also very irregular. The hanging or upper side of them sometimes rises up into a concavity, quite out of the regular flat course of it, and sometimes again it falls down into a convexity. The ledger or lower side of these veins are often also irregular, falling into concavities and rising up to convexities."

The Pipe Vein resembles in some respects a huge irregular cavern pushing forward into the earth in a sloping direction, but varying considerably in their angle of inclination; they are found indeed in all positions between the perpendicular and the horizontal. The pipe vein is bounded by rocks on all sides; in general it does not cut the strata like the rake veins. Some pipe veins are full of solid ore, others are mixed with spar and rider. They sometimes open out on the right and left hand to a great many fathoms wide, and it frequently happens that they rise up into the roof and sink down into the sole at the same time, so that the *pipe* which perhaps was not before much above a fathom high and a couple of fathoms wide swells out suddenly into a prodigious belly which in bearing pipes proves immensely rich. In Denbighshire, Williams "saw them working a pipe vein no wider than a good mining-shaft or a coal-pit. This pipe was almost round, and it was put down in the rock with a slope between the angle of 45° and the perpendicular. It was quite full of good ore about 6 feet diameter."

The veins in the northern division of Derbyshire run from Castleton generally south-west, two or three veins only deviating to the north of west. The great lode from Great Hucklow, after running for some distance east and west, takes a deviation of about from 10° to 15° north of west. The lodes to the south of Tideswell generally run north of west, until, in the High Field and near Taddington, they all run in a south-westerly direction; this is the case until, after passing Taddington, High Moor, and advancing to Sheldon, we find at the Magpie mines one lode running east and west, while a lode from Grey Marble quarry to Monsall has a direction from south of east to north of west, and one lode at Maddon Vale runs nearly magnetic north and south. At and around Middleton, and on Middleton Common, the lodes are within certain limits exceedingly irregular. At Ladywell Mill the bearing is generally north of west. In the detached Limestone field of Warslow we have four lodes running north and south, three have a westerly direction, and two north-west. The lodes at Keywell Green and High Moor are, two of them north and south, two north-

west and south-east, one due east and west, and two south of west. In the centre of the Limestone, a mile south of Witton, we find a group of lodes, seven of which have a direction north of east, and two south of west. The lodes on the lower south-western edge of the Limestone are unimportant, but three of them take a south-westerly direction and two a north-westerly one. It is not an easy matter to make these conform to any system, and but little difference has been observed in the produce of the lode, whatever direction the lodes may take.

The Streck, Flat, or Dilated Vein.—The flat, or dilated vein is a space or opening between two strata, in like manner as the roof and pavement of a stratum of coal are above and below that coal. These flat veins are found between the strata, in several species of stone, but they are most frequently found in Limestone, lying either in a horizontal or declining position. Williams remarks some English miners call the flat veins *streeks*, and when they have both, a *rake vein* and a flat vein in the same field, they distinguish them by the appellation of the *vein* and the *streck*. By the word *streek* they signify stretch—or a vein between the strata, which spreads or *stretches* in a horizontal position. Williams says the *flat* or *strata* veins are not fissures or gashes in the strata, *but they are always found between the strata*, and are themselves imperfect strata, or at least each of them occupies the place of a stratum; so that there is always a very wide difference in the theory of these two species of veins. The rake vein being always a longitudinal fissure or break *across* the strata in some line of direction, in which case the vein is the chasm, or space between the sides of that longitudinal fracture, whereas the *streck* or *flat* vein is a space between two layers of stone, which space is generally filled with some mineral matter or other.

The flat vein is not, it must be remembered, the *space* between two beds of stone, but the mineral matter which fills that space. As a bed of coal lies in the Coal Measures, so does a flat vein of lead lie between the beds of Limestone. These veins have always the same horizontal or inclined position as the strata has in which they are found, and they are liable to dislocations, throws, slips, dykes, &c., as is a coal bed. "With this difference," says a good miner, "that in working the coal these interruptions are generally real troubles, and getting over them is so much pure loss of money and time; whereas, on the contrary, when they are met with in working a flat vein they often prove of a great advantage, as they are, in fact, other mineral veins of different denomination and description, so that as often as these interruptions are met with in the *flat vein* it is an adventitious increase of the reality, or at least the chance of meeting with more treasure in the same field." It must, however, be remembered that flat veins are not necessarily horizontal; nor are they always found between the strata, having of necessity the same declivity as the beds between which they lie. The *flat veins* of Cornwall—for example, those of Carn Brea Hill —are regular fissure veins dipping but slightly. The *carbonas* of St. Ives and Providence mines are another form of flat veins. Sometimes the flat veins of Derbyshire will continue of a moderate height between the roof and sole for a considerable distance, and then the roof and sole will come together, and open again, after it has travelled a short space. It sometimes happens

that the flat lode or *streek* opens out into large *bellies*, although they are more frequently in flattish *glebes* or masses, in which case they resemble the carbonas yet more closely.

Several attempts have been made to describe the way in which the ore is deposited in these *flat* veins. The space, or bed, between the layers of rock may have been subjected to various disturbances, but these must be regarded as purely accidental. It so happens that a space is left open between the beds of the same rock—let us say Granite—or between the dissimilar strata of a newer country; and this space, corresponding to the general dip of the beds of the district, has been filled in with metalliferous matter of some kind, be it tin, or lead, or copper, or iron.

Slip Veins are seldom wider above than below; the sides of the fissure are closer together at the superficies of the strata than at greater depths. These veins are subject to *checks* or *twitches* when the two sides, or *hanger* and *ledger*, come close together, and no cavity or open space is left between them.

Gash Veins, on the contrary, are always wide open above, and grow narrower in depth, and they often close, or *check out* below altogether. Williams mentions two remarkable examples of the gash vein, one at Strontian, in the Highlands of Scotland, and the other at Llangurrig, in North Wales. Of this last he remarks: "This rich and noble vein was at once cut out below by a black schistus or *shiven*, so that no vestige of the *vein* was left, nor ever afterwards could be found."

The swells or wider parts of the vein often remain unfilled, and are frequently found opened; these parts are in Derbyshire known as *tick-holes*, *jouph-holes*, *druses*, *nests*, or *locks*. These cavities are always filled in with the most perfectly crystallised specimens of the mineral ores. Farey remarks of the Derbyshire mines: "But in the greater number of cases, particularly where the *tick-holes* or empty spaces in the vein were large, a confused and coarse kind of crystallization, often of a stony texture in part, has completely filled up these cavities, sometimes without the admixture of any ore, or perfect spar. These stony masses are called *riders*, I suppose from the circumstance of their always resting upon spar (and ore for the most part), and never touching the *vein-skirts* or rock in which the vein is formed."

A Kindly Lode is a mineral vein which contains metalliferous ore, and holds out a promise of its being continuous.

An Unkindly Lode is applied to a vein which contains little or no ore, and which is regarded by experienced eyes as very unlikely to produce anything to profit. The Country is also spoken of as kindly or unkindly according to the peculiar conditions which it presents to the experienced miner's eye.

A Dead Lode is a mineral lode which contains no metalliferous ores. *A living stream* or a *lively lode* was applied by the old miners to productive deposits or veins.

Flying Veins is a term used by miners to signify a broken, discontinuous, irregular vein.

Mineral veins are of very varied composition, and they often receive from the miners names expressive of the peculiarities they exhibit as it regards their contents.

A Mundicky or *a Mundic Lode* is one that is filled with iron pyrites,

whether this be a combination of sulphur and iron or of arsenic and iron. It often happens that a lode bearing mundic near the surface, and at a little depth begins to show copper pyrites—the yellow copper ore—in depth becomes a good copper lode.

A Peachy Lode is one containing a considerable proportion of *Chlorite*. Such a lode promises more frequently for tin than for copper, although in many mines—for example, at Polgooth, Relistian, Wheal Unity, and others—yellow copper ore has been found mixed with Chlorite. Copper ore in Chlorite was also found in the Wherry mine, in the Mount's Bay, already described.

Chlorite (from χλωρὸς, *green*, known in Cornwall as *peach*) is composed of small pearly, glimmering, scaly particles; it has a somewhat greasy feel, and bears a resemblance to green earth. It occurs in the tin lodes of Cornwall and in the mines of Cumberland and Westmoreland. Bristow* gives an analysis of Chlorite from the Pyrenees, by Delesse, as follows:—

Silica	32·1
Alumina	18·5
Magnesia	36·7
Protoxide of Iron	0·6
Water	12·1

Chlorite sometimes contains as much as 8 or 9 per cent. of protoxide of iron. Those kinds which have more protoxide of iron are classed with Ripidolite, which sometimes gives 28 per cent.

A Flucany Lode, or flukan vein, is one in which the walls or sides on either one or both sides are lined with a whitish or bluish clayey substance, or when it is diffused through the lode itself. A *flucan* is a small fissure filled in with clay.

A Scovan Lode is when tin ore is mingled with quartz and Chlorite—which is of a dark brown or of a dirty greenish hue—due, I believe, to the state of oxidation in which the iron exists. Generally such a lode is not hard or compact.

A Sucked Stone is a lode which is rarely more than 12 inches wide, and it occurs sometimes in a mineral vein, the contents of which are not solid; hence the term: the miner's hypothesis being, that the main lode has drawn off all the ore from this inferior one.

A Capley Lode consists of hard and unpromising substances, generally greatly intermixed with minute portions of Chlorite. Tin is often found in a capley lode, copper rarely. But if a branch of copper ore, or a gossan, be found to take its course down the vein, it commonly makes a durable mine.

A Pryang Lode (*pry* is Cornish for *clay*). When tin or copper ore does not occur in a compact state, but the stones are found mixed with flucan or gossan, it is so called.

Black Jack Lode is one that abounds in Blende—sulphide of zinc. It is considered a favourable indication for copper. "*Black Jack rides a good, or a proud, horse*," is a common expression with copper miners.

A Growan Lode (*growan* signifies *gravel* in the Cornish language, according to Borlase). A lode, therefore, filled with fragments of decomposed Granite is called a growany lode. In the Granitic districts it often happens. But

* Bristow's "Dictionary of Mineralogy." Longman & Co.

growany lodes are productive of copper ore. *West Wheal Virgin*, *Carharack*, and *Wheal Damsel*, in Gwennap, are cases in point.

A String in mining is a discontinuous vein or mineral fissure, which extends from the principal vein and starts from it at an acute angle, "and when it has stretched in that line to an indeterminable though no great distance, it then terminates in a point, the two sides coming together." Strings are, in fact, small fissures or cracks extending from the main lode, and are doubtless the result of the same force which rended the rock; and as the larger fissure was produced those smaller rents were developed. These strings fly out from the vein in all directions, but always diagonally. They are sometimes very rich.

A Bar is a short vein which runs right across, or in a diagonal line between two parallel veins, joining them as does the bar in the letter H.

A Skew is an irregular mineral fissure starting out from the main lode in an uncertain direction, generally lying in a slanting irregular position.

A Back is a fissure which often resembles a segment of a circle. "The back breaks off from the hanging side of a vein, strikes out to a less or greater distance, fetches a sweep, and comes back into the same vein again at a distance from where it sets" (*Williams*).

Guide.—A name given by the miners to iron veins or cross courses, or rather to veins which are filled, or nearly so, with iron ochre, especially as these veins are seen in the cliffs on the western coast of Cornwall, yielding neither tin nor copper. Examples may be seen in St. Just, at Wheal Owls Point, at Portnanven Cove, and at Caragloss Head.

Trawns, in St. Ives district, are similar to the guides: poor lodes, composed of clay or filled with quartz, are so called.

A Rider.—A vein-stone, which is generally concretionary, found in the middle of a mineral lode. "This compound stony concretion is called by miners a *rider*, perhaps from its *riding* in the vein, or separating it longitudinally into two or more parts" (*Williams*). The mineral character of a rider, which is sometimes called a "*horse*," may vary considerably. It is frequently fragments of the enclosing rock cemented together by lime or by silicious matter. It is sometimes a crystalline formation which has from a small beginning gradually accumulated into a large mass, and eventually been surrounded with the metalliferous matter of the vein itself. Williams, with some reason, says: "I call this vein-stone, as I think the term should be most intelligible to naturalists, it being always found in veins, upon the superficies of them, and in fragments and masses lying about upon the face of the ground, which have slidden or been forced off the superficies of veins."

It is not unusual to find a large body of *rider* in a large or, as the miners term it, a *strong* vein, standing in the middle of the vein like a wall, with a space between it and the sides of the vein, dividing the vein in two. These large masses of rider are frequently very hard. The masses of rider lodged in the soft matter found in wide, loose veins are sometimes rich in ore; but usually they contain but little ore, and sometimes none at all. The miners, when the riders are rich in metalliferous matter, call these "*masses of ore mixed with rider*;" when they are poor they always speak of "*riders mixed with ore*." Such masses are in Scotland and some other places called

"*glebes*," and the soft soil in which these riders are found is called by the Scotch miners "*mother*," as schorl (tourmaline) is in some districts of Cornwall called the "*mother of tin*." When a seam of clay occurs between a rider and the walls or sides of a vein, it is called by the miners a "*steeking*;" if it is but a thin vein of clay they call it a "*sticking*."

Bellies of Ore or Matter are large masses, generally isolated, found either in the vein or in the rock. Strictly, however, the *belly* is a dilatation of the vein itself to a great width. Large accumulations of ore in the earth-caverns in the Limestone have been in the process of time filled in with metalliferous matter, generally lead. This would be called by the miners a belly.

"Sometimes the sides of a lode are parallel, and sometimes they recede from each other, so as to form large accumulations, or, as they are called, *bellies of mineral matter*."*

A Waving Vein is a perpendicular fissure which opens and closes within a short distance. A miner describing it will say it consists of "bellies and *twitches*." These twitches, or grips, are contractions in the vein, and they are generally thought to indicate unproductiveness.

The Accumulated Vein.—Williams, in his "Mineral Kingdom," gives an important place to this peculiar lode. His description of it, however, goes to show that it is really only an enlarged pipe vein. He says: "The accumulated, concentrated, or conical vein is not easily described so as to convey a distinct idea of it. Some of these veins approach to the form of vast irregular cones, and others of them have some resemblance to inverted cones; but, whatever is the form or description of this mineral repository, it generally contains a great deal of wealth in a small compass of ground, the accumulated veins being often the richest of all mines." . . . "The main pipe or shaft of the accumulated vein resembles the inside of a glass house, and the vast capacity of this vein is often stored with a rich body of metallic ore, frequently bedded with soft mineral soil, but the veins and branches which join this pipe and diverge from it commonly resemble our rake veins or perpendicular mineral fissures."

It sometimes happens that a great number of perpendicular fissures meet and join in one common centre, from which they spread out or radiate to different distances of the shaft or cone, and these branches frequently contain rich bodies of ore.

"We see nothing," says Williams, "in the practice of mining so awful and tremendous as the excavation of large accumulated veins which have proved rich in ore. The mining shaft or pit for drawing up the ore and for descending down to the works is frequently sunk upon the vertex of the cone or perpendicular pipe; and when you descend 50 or 60 fathoms down in one of these shafts, you are then swinging in the middle of an immense void space, where you see on all sides rugged, frightful, hanging rocks, which threaten to fall upon you and crush you to pieces."

The hade of veins is the mining term, in Alston, for that inclination which nearly all veins have from a perpendicular direction. Thus a vein is said to *hade to the north* when it inclines farther north as it deepens. In Allendale

* "Law of Mines and Minerals." By William Bainbridge.

and Alston most of the veins *hade* to the north. In Weardale the veins generally *hade* to the south. This hade or inclination is not always uniform. It varies with the strata, being determined indeed by the character of the rock through which it passes. Sopwith gives an interesting instance of the importance of attending to the hade of a vein. A freehold estate of thirty or forty acres was purchased for £1,500. A vein leased from the Dean and Chapter of Durham ran parallel with, and at a short distance from, one of the boundaries of the purchase, but the vein *hading* into the royalty of the said estate, the proprietor received from the lessee one-fifth duty, which amounted to about £800.

The Throw of veins is the usual mining term for that vertical disruption of the strata which generally occurs near veins of magnitude. There is a remarkable correspondence between the *hade* and the *throw* of veins. The following rule applied in Alston Moor. "If an east and west vein throws the strata up on the south side of the vein, then the hade of that vein is to the north, and the contrary strata are thrown up on the north side, and so of all other veins." The hade is usually opposite the side on which the strata are highest on the ledger side of the vein. The variable throw of veins is illustrated especially in the lead lodes of Alston Moor.

East and West Lodes are distinguished by the direction in which they lie. An east and west lode is a metalliferous vein whose direction is not more than 30° from these points.

Contra Lodes are metalliferous veins whose direction is beyond 30° and not exceeding 60° from east and west. The miners give the name of a *contra* lode to every lode which is much out of an east and west direction, and which crosses the lodes running east and west.

Cross Courses are fissures or veins whose direction is not more than 30° from north and south.

Cross Flukans are veins of clay having the same direction as the cross courses.

Slides are thin veins of slimy clay, the result of movements in the rock or mineral lode, generally greatly inclined, and having commonly an east and west direction, rarely running north and south.

Heaved is a term used as applicable only to a *longitudinal shift* of the rock or the lode.

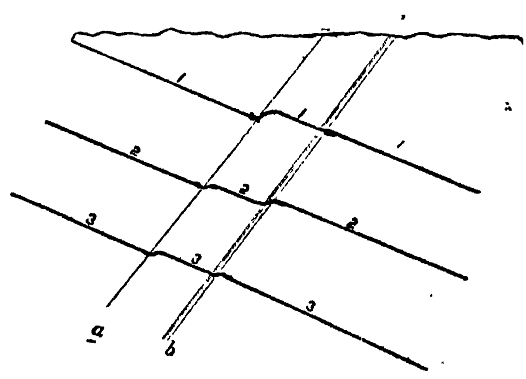


Fig. 36.—Heaves at Sealhole Mine.

Mr. Carne divides tin lodes into two classes—the *oldest tin lodes*, and the *more recent tin lodes*. This division is founded "on several instances which have been discovered, where, at the meeting of two tin lodes, one of them is traversed and *heaved* by the other. In other words, the great tin lode in the plan, *a b*, Fig. 36, had its origin subsequently to the formation of the three

lodes, 1, 2, 3;—in a disturbance producing the crack or fissure *a b*, by which they were broken and moved, the filling in of the more recent tin lode being effected after the disturbance—*the heave*—had completed its work. The tin lode of Wheal Owls in St. Just runs nearly north-west and south-east, and traverses every other tin lode which it meets. It is generally stated that the tin lodes which underlie northwards are traversed by those which underlie towards the south. I conclude, therefore, that the *former*, which form a very large majority of the whole, are the oldest." That these lodes are traversed by other tin lodes, which underlie in an opposite direction, is evident by examples in Sealhole mine, Wheal Coates, Wheal Owls, and Wheal Trevaunance.

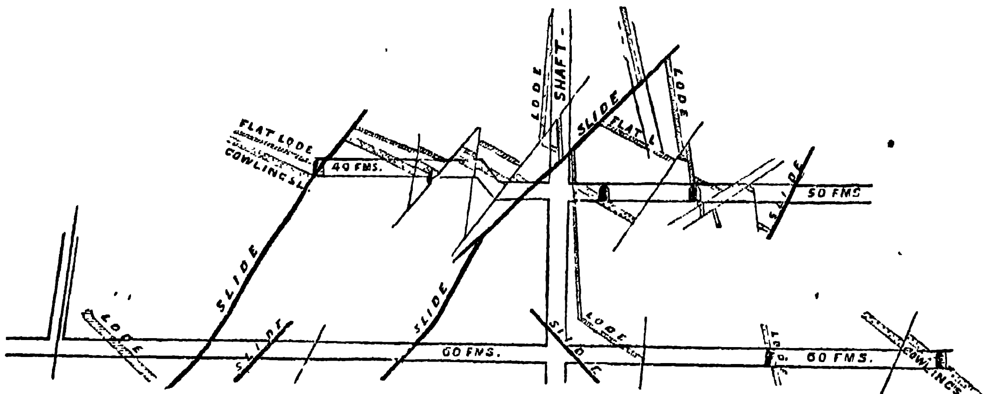


Fig. 37.—Dislocations in Penhalls Mine.

A most remarkable example of several of these dislocations, producing a series of remarkable *heaves* in the *lodes*, exist in *Penhalls* mine in St. Agnes (Fig. 37). We have evidence of four *slides* occurring in one direction, and of a fifth *slide* in a contrary one. These shift the lodes to a considerable extent, in each case down to the sixty-fathom level. In several instances there are *heaves* acting independently of the slides, throwing the lodes up or down, and producing the dislocations, which deserve a close study.

Thrown up or *Thrown down* are terms used to indicate that the lode has been moved by some disturbance in one direction or the other.

Thyrlings is a term usually employed by colliers,—but it is occasionally used to express, in the lead mines of Durham and Northumberland and Derbyshire, a mark indicating the termination of a "sett" or of a "pitch," as "A predecessor of the defendant, but with whom he had no privity, committed a trespass and made holes, called *thyrlings*, in a barrier of coal belonging to the plaintiffs, which separated the two collieries." *

Heaves are said to be either *right-hand* or *left-hand* heaves. This signifies that when a lode is dislocated and moved by the interference of another lode, it may be found on the other side of the traversing lode either to the right hand or to the left hand. This is thought to be in practice more readily understood than the points of the compass.

The more recent tin lodes comprise most of those lodes which underlie southwards. A few mineral veins in *St. Agnes* have a southern underlie. The valley of Nancherrow in St. Just divides the parish of St. Just in a

* As applied in Coal mining, see "Collieries and Colliers." By John Coke Fowler.

direction east-south-east to west-north-west. South of this valley all the lodes underlie north. North of the valley the lodes generally underlie south. Some deviations from this exist on both sides of the valley.

The ages of the lodes become a very important consideration, and we are greatly indebted to Mr. Carne for his investigation of this involved subject. It is to the tribute-miner often a problem of considerable importance to determine the relative ages of two lodes. Mr. Carne lays it down as a law, "*That a vein which is intersected or traversed by another vein is older than the vein by which it is traversed.*" Borlase* had previously speculated on this being the case, and he quotes Hutchinson's authority for it. Pryce,† in his work, plainly laid down this rule, and Werner‡ puts great stress upon it.

It will be advantageous to state at once that the following remarks on the ages of veins are entirely based,—so far as the tin and copper veins are concerned,—on the paper already alluded to by Mr. Carne.

The oldest tin lodes are indicated by being traversed and *heaved* by others. As a general rule, the tin lodes which underlie northwards are traversed by those which underlie towards the south. Therefore those which underlie north—and these are the largest number—are the oldest. *The more recent tin lodes* comprise most of those which underlie southwards.

In the oldest class of tin lodes must be included most of the *lodes* in the tin-producing parishes of St. Agnes and Wendron, and a considerable number of those in St. Just, and those also in the mines of Wheal Vor, Great Hewas Down, Wheal Unity, Pedenandrea, Relistian, Trevaskas, Nangiles, &c.; indeed, the principal lodes in the great tin-producing districts.

The term *heaved*, as used by the miners to signify a longitudinal shift of the vein,—and *thrown up*, or *thrown down*, to those shifts which take place on the meeting of two veins, underlying in different directions, in their downward course, requires some explanation

It should be understood that this mode of expression, which a stranger to mining language may mistake for an *active* movement of the lode, signifies, only, that there has been a movement of a mass of the Earth's strata, and, consequently, that a lode which existed as a continuous line, is broken, and that on one side of the fissure formed, it has been moved either up or down, as the case may be.

In describing the *heaves of lodes*, as to the right hand or to the left, it is meant that when lodes are *heaved* they may be found on the other side of the traversing vein by turning either to the right or to the left hand.

Sir Henry de la Beche gives the following very clear definition: "There would appear little doubt that numerous apparent *heaves*—as the Cornish miners term these dislocations—are nothing more than contemporaneous fractures, with a considerable shift among the various fragments, both great and small, produced at the same time. The best evidence of the priority of one set of fissures to another, consists in the general fact that the body of the country containing the ore is so moved, where traversed by the other, that the one set merely occupies its general position in

* Borlase's "Natural History of Cornwall," p. 156.
† Pryce's "Mineralogia Cornubiensis," p. 101.
‡ Werner's "New Theory of the Formation of Veins," p. 51. (Anderson's translation.)

the country, like any particular beds or masses of rock in following the general shift, while the other set passes directly through all, cutting across and destroying the continuity of the contents of the other set, in common with the general rocks of the country. Thus, in the annexed woodcut (Fig. 38), which represents a general plan, on the scale of one inch to a mile, of part of the Great Cross course *a b*, near Redruth, where it traverses the North Downs, all the *lodes* or mineral veins *l l*, are moved with the body of the country, as shown by the *heave* of the Elvan courses *e e*, and of the junction line of the Granite *g* with the Slate *s s*. In such a case it can scarcely be doubted that *a b* is a fissure formed subsequently to the fissures marked *l l*.

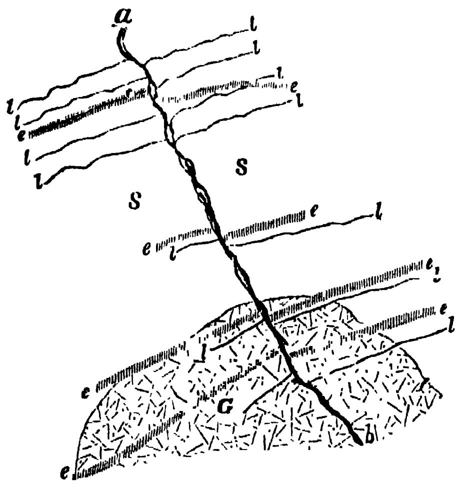


Fig. 38.

"A few more words explanatory of the dislocation of one set of fissures, by another formed at a subsequent period, and to the *heaves* which may be produced *apparently contradictory* to each other by the same movement, may prove of use.

"*a b* in this section, Fig. 39, represents the surface of a country traversed by the Elvan courses *e e* and by the lodes *l l*. Suppose this country to be dislocated in a plane perpendicular to the section before us, so that *a' b'* on the one side be lifted vertically above *a b* on the other. It will be seen that on the level *a b*, though the amount of vertical elevation has been common to all the *lodes* and *Elvan* courses, these have, according to their various dips or underlies, very different relative distances from each other on the one side than on the other.

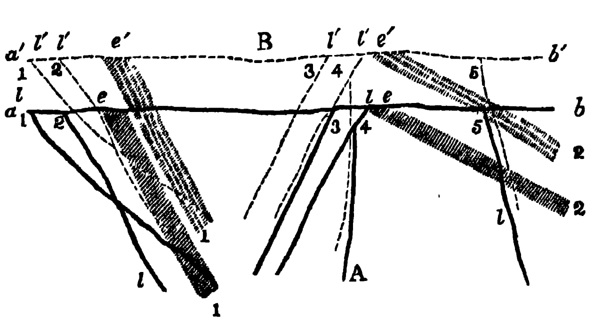


Fig. 39.

"This will be still further illustrated in a plan, Fig. 40. While the *lodes* l^1 l^2 and the *Elvan* e^1 are *heaved* to the right on the side of the dislocation marked B, the lodes l^3 and l^4 are heaved to the left, and in the latter case a lode, or branch from a

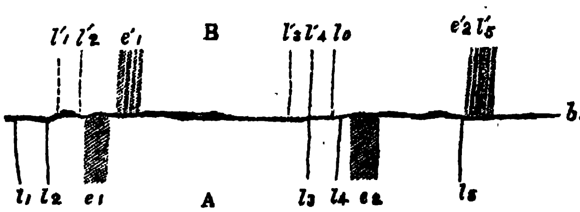


Fig. 40.

lode, l^0 appears on the side B which was not on the surface on the side A, so that three lodes appear on the side B as continuation of the two lodes visible on the surface at the side A. The Elvan e^2, which was close to the lode l^4 on the side A, is apparently removed far from it on the side B, and, moreover, contains the *lode* l^5 in the latter case, which was far removed from it on the side A."

In connection with these movements it is necessary that the theories of M. Élie de Beaumont should be understood.* The "Mountain System," as he terms it, commences with definitions, and with these we are chiefly concerned.

Fractures effected in the exterior crust of the Earth have determined the elevation and uplifting of the rocks of which this crust is composed, and the crests of these broken and upturned beds of rocks form the summits of those asperities of the surface of the globe which we call *mountain chains.*

Links are either *straight* or made up of straight elements, to which we may give the name of *links*. The different "links" observable over a large extent of country, though presenting great variety of direction, are mostly connected with a limited number of *orientations*. Each group of mountain links, or *topographic accidents*, characterised by frequent repetitions of these orientations, is what we call a mountain system.

Relative Age.—The parallel links which constitute a mountain system are contemporaneous. In each mountain range the sedimentary bed may be divided into two classes. The more recent beds are horizontal right up to the flanks of the mountains; the others, on the contrary, are *upheaved*, and rest upon those flanks, and sometimes are even elevated to form their crests.

Stratigraphic Systems.—This term includes the great foldings of the Earth's crust—mountain crests, upheavals, inclinations and plications of the beds, and fractures of different kinds—which have been produced at the same epoch under the influence of rectilinear movements acting in a direction parallel to the direction of a system. *Stratigraphy* is that part of geology which is occupied with the geometric description and the graphic representative of mineral masses.†

The next subject for consideration is the relation of the throw of veins to the dip of the strata.

Mr. W. Forster observes that the east and west veins of Weardale generally throw the north cheek up and *hade* south; most of those in Allendale and Alston Moor throw the south cheek up and hade north. In Alston Moor the dip of the strata is northward, and thus dip, hade, and throw coincide. In the Swaledale district the dip of the strata across the veins is very inconsiderable either way, and the throws of the beds are partly north and partly south.

At Grassington the veins range north-west and south-east, and east and west (the former are the strongest and best veins). They nearly all throw down to the south, and hade and underlay in the same direction.

In the Greenhow mining field the prevalent directions are west-north-

* "Notice sur les Systèmes de Montagnes." Par L. Élie de Beaumont. 3 vols. 8vo. Paris: 1852.

† For a more complete elucidation of the author's views, the English reader should consult the admirable translation of Professor L. Moissenet's book, "Observations on the Rich Parts of the Lodes of Cornwall," by J. H. Collins, F.G.S. 1877.

west and north-west, as at Grassington. The veins go through and cross the axis of elevation, ranging east by north.

These observations render it apparent that the number of mineral veins is regulated by the proximity of great lines of fault and anticlinal elevation, and that their east and west direction is, in the region of the Penine fault, variable in relation to such. Where the Cross Fell fault ranges north-north-west it is rectangular to the right-running veins, and parallel to the cross veins; where it ranges south-south-west it is still rectangular to the majority of the veins.

Of *veins which cross*, it has been noticed in the north of the Penine region that the east and west veins are commonly divided by the north and south veins, and therefore receive the name of *cross courses*. Werner has been almost universally followed in asserting that *cross veins* are of later origin than the others, because *they cut through them*.

Mr. Hopkins very truthfully says: "There is an intimate relation between the *faults*, more particularly the longitudinal ones, and those great fissures in the crust of the globe with which, as *mineral veins*, we are acquainted. The veins seldom coincide with the faults, but run near and parallel to them, clearly showing that whatever cause may have produced the one class of phenomena must also have produced the other."*

In studying the constitution of rock masses we find not only the bedded structure, but we have indications, more or less numerous, of divisional planes traversing the beds at various angles, often nearly approaching the vertical. In many cases these planes are so thickly manifested and so regularly produced as to occur in thin laminæ.

"When," says De la Beche, "therefore, we see two series of divisional planes alike traversing igneous rocks and sedimentary deposits, one series being either vertical or very highly inclined, the planes varying from a few inches to several feet apart, and the other series, not so generally common, having the planes so close as often to divide the rock into thin laminæ, we are led to suppose that powerful forces, tending to render the mass crystalliferous, have been in action, and that these two kinds of divisional planes are their effects."

The miner has through all time observed the jointed structure of rocks, and, as those joints indicate the lines of least resistance, he has made use of them to facilitate his operations in rending them.

Some joints traverse the rocks without any interruption; some coincide with the *lodes*,—some with those of the *cross courses*,—and others with the direction of the *Elvan courses*. A little thought will convince any cautious observer that the relations of one to the other are different. The Elvan courses are evidently the result of the fusion of Granitic matter which has been *forced* by enormous pressure through the rocks. The Elvan may, indeed, have led to the fissuring of the rocks through which they pierce. Therefore those joints which coincide with the direction of the Elvans are due to the mechanical force brought into action by the power of the injected matter. The joints corresponding with the lodes were no doubt produced by the same force which caused the fissures in the rocks, which were subsequently filled

* Mr. W. Hopkins, "On the Stratification of the Limestone District of Derbyshire." 1834.

in with vein-stuff (the matter forming a true mineral vein). The joints coinciding with the *cross courses* will have been formed by some similar mechanical force, acting at nearly right angles to the force producing those which correspond with the lodes. These joints have long been recognised, but their coincidence with mineral veins and the fact of their uniformity for considerable distances have only been pointed out of late years.*

The joints in rocks are frequently almost indistinct until they are developed by the influence of slight decomposition, resulting either from the percolation of water through them, or from atmospheric influences. Mr. Henwood remarks: "On this account it is often very difficult to determine which is the principal series; because their exposure to degrading causes in one direction more than in another will occasion the appearance of one set of joints in one place, whilst in another a similar cause may operate in a different direction, and bring out another system of lines. Hence within a very short distance the principal joints may seem to run at nearly right angles to each other." He appears in this rather to confound two systems of joints, the result of forces acting in directions at nearly right angles to each other.

The jointed structure of different strata is subject to considerable variation. The Slate rocks are generally divided diagonally into *triangular masses*. In Granite the divisions produce more or less cubical blocks. Sometimes the joints will preserve a tolerable amount of regularity for some distance, and then exhibit considerable flexures on the lines, both of direction and dip.

Often the diagonal joints unite with one of the others, and not unfrequently one of the rectangular joints swerves from its course and continues for some time as a diagonal one. Mr. Henwood devoted a large amount of attention to the examination of rock structures. He thinks there are two series of divisional planes that are permanent, whilst a third is less constant. This excellent observer constructed a table giving a general view of the direction of the joints in the different mining districts. This is so instructive, and bears so importantly on the formation of mineral veins, that it is given entire.

DIRECTIONS OF THE JOINTS OR LINES OF SYMMETRICAL STRUCTURE IN THE ROCKS.

GRANITE.

Districts.	N. to 10° W. of N.	10°—20°	20°—30°	30°—40°	40°—50°	50°—60°	60°—70°	70°—80°	80° W. of N. to W.	W. to 10° S. of W.	10°—20°	20°—30°	30°—40°	40°—50°	50°—60°	60°—70°	70°—80°	80° S. of W. to S.
St. Just . .	—	—	3	—	1	—	—	—	1	—	—	—	—	—	—	—	—	1
St. Ives . .	—	—	1	1	3	—	3	—	—	1	—	3	1	—	—	—	—	—
Marazion . .	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Gwinnear, &c.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Helston . .	1	1	—	1	2	—	—	—	—	—	1	1	1	—	—	1.	—	—
Camborne, &c.	2	1	—	—	2	—	—	—	—	—	1	—	—	1	—	—	—	—
Redruth, &c. .	2	—	—	—	—	—	—	—	—	—	—	3	—	—	—	—	—	—
St. Agnes . .	1	—	—	—	—	—	—	—	—	—	1	—	—	—	—	—	—	—
St. Austell .	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Tavistock, &c.	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

* Dr. Berger, Professor Sedgwick, Dr. Boase, Professor Phillips, Mr. Enys, Mr. R. W. Fox, Mr. Hopkins, and Sir H. de la Beche have each, and all, devoted much attention to the jointed structure of rocks.

DIRECTIONS OF THE JOINTS OR LINES OF SYMMETRICAL STRUCTURE IN THE ROCKS—*Continued.*

SLATE.

Districts.	N. to 10° W. of N.	10°—20°	20°—30°	60°—70°	70°—80°	80° W. of N. to W.	W. to 10° S. of W.	10°—20°	20°—30°	30°—40°	40°—50°	50°—60°	60°—70°	70°—80°	80° S. of W. to S.
St. Just . .	—	—	—	—	—	1	—	—	—	—	—	—	—	—	
St. Ives . .	2	—	—	—	—	—	—	1	—	—	1	—	—	—	
Marazion . .	12	—	—	1	—	5	—	1	—	—	4	—	1	—	
Gwinnear, &c.	2	2	3	—	1	—	1	4	—	1	2	—	—	—	
Helston . .	2	1	—	—	—	—	—	1	—	—	2	—	2	—	
Camborne, &c.	3	2	—	—	—	—	—	—	1	—	2	—	—	—	
Redruth, &c. .	5	1	—	—	—	1	—	2	2	2	3	—	—	—	
St. Agnes . .	8	1	—	—	1	4	—	2	4	—	1	—	—	—	
St. Austell .	5	—	—	—	—	2	—	1	—	—	1	—	2	—	
Tavistock . .	3	—	—	—	—	5	—	1	—	—	—	—	—	—	

Mr. Henwood furnished a table, relating also to Elvans, but all the conditions of this *intrusive* rock are so very different from those of Slate or Granite, that the direction of the joints are not in any way instructive, and the observations made have therefore been omitted.

When the planes of lamination traverse different beds, interruptions of the even course of the lamina are often, though not always, observable; they frequently are bent and undulate. It would appear as if the "laminating forces" (whatever they may be) had suffered interruption where they encountered the open spaces between the beds, filled probably with water, containing, as usual, mineral matter in solution. Professor Sedgwick remarks * on the lamination planes observable in North Devon: "The whole region is made up of contorted strata; and of the true bedding there is not a shadow of a doubt. Many parts are of a coarse mechanical structure, but subordinate to them are fine crystalline chloritic slates. But the coarser beds and the finer, the twisted and the straight, have all been subjected to one change. *Crystalline forces* have rearranged whole mountain masses of them, producing a beautiful crystalline cleavage, passing alike through all the strata. And again, through all this region, whatever may be the constitution of the rocks, the planes of cleavage pass on generally without deviation, running in parallel lines from one end to the other, and inclining at a great angle to a point only a few degrees west of magnetic north."

Although the direction of the present magnetic meridian in the district is temporary, and the tendency of the divisional planes to it is accidental, yet their prevalence in both igneous and sedimentary rocks leads us to suppose that electric forces governed the arrangement of the component parts of rocks, and consequently determined the arrangement of mineral veins. Dr. Boase, a close and thoughtful observer, remarks that the integrant particles of rocks are combined and arranged in forms more or less geometrical. Their complicated composition may possibly account for their not presenting the same regularity as perfect crystals, "so that their forms are not the simple result of the aggregation of similar particles, but the balance of different powers each tending to produce a different form." † It

* Sedgwick, "On the Structure of Large Mineral Masses" ("Geological Transactions," Second Series, vol. iii. p. 477). The influence of crystalline forces has not received the attention it deserves. Professor Sedgwick is the only geologist of note who appears to appreciate its enormous power.

† Boase's "Treatise on Primary Geology."

should be remembered that the magnetic meridian is not a constant line, but one subject to a variation which is very fairly determined. The following are the magnetic elements for 1882 inferred from observations at the Royal Observatory at Greenwich:—

Declination (or variation of compass)	18° 20′ W.
Inclination (or dip of the needle)	67° 32′*

In 1833 Mr. Enys, of Enys, stated that the vertical divisional planes or joints of the Granite near Penryn took a general direction from north-north-west to south-south-east, varying but a few degrees from these points, this being the most constant direction for the Penryn district. On the northern part of Dartmoor the Granite was not only cleaved perpendicularly in this direction, but also on lines at right angles, or nearly so, to it.† To show the average amount of local variation, Sir Henry de la Beche gave several careful measurements of the divisional planes.

At Peden-maen-du .	325°
Near Carn Cloy .	325° to 242°
Near Carn Creis .	318°
At Nangisal or Mill Bay	315°
At Carn Barra .	318°
At Carn Mellyn .	325°
At Tol-Peden-Penwith	316° and 218°
At West Porth Chapel	320° and 225°
At Peden-maen-anmear	320°

Taking the present magnetic north to be about 335° at the Land's End, it will be seen that the average of the whole differs by about 13° or 14° from it. The great divisional planes in the Serpentine of the Lizard approach very near to the present magnetic meridian. As a whole, the great divisional planes of the district may be said to prevail more in directions from north to north-west and from south to south-east than in others, the greatest number holding their courses within a few degrees of north-north-west and south-south-east, these lines being cut by others which chiefly form angles from 70° to 80° with them. In addition to these great divisional planes we have the result of some physical force which has been, by some, referred to electrical currents, and by others to mechanical force, by which planes of lamination divide the rock into thin plates.

The *crystalline forces* referred to above must be considered to be a peculiar form of a cohesive power, acting with *polarity*, and thus producing a geometric figure. The author is impressed with a belief that he has shown that electro-magnetic force has much to do with this symmetrical arrangement.‡

It has been already stated that by long-continued slow electrical action a schistose structure can be produced in masses of clay, and we shall presently have to discuss the influence of the same force in producing

* In 1836 the committee of the Royal Cornwall Polytechnic Society determined to furnish the means by which the true meridian could be accurately determined. The spire of St. Kevern Church on the south coast was fixed on as the southern extremity of the line, and they erected a granite pillar in a field to the westward of Beacon Hill to mark its other extremity near Falmouth. This gives a base line of about 40,000 feet. By this line compasses and other mathematical instruments can be accurately adjusted; and mine agents and surveyors are enabled to lay down their plans to the true meridian.

† "On the Granite District near Penryn, Cornwall," p. 254. By John S. Enys. London and Edinburgh. See also "Remarks on the Intensity and Quantity of the Junction Changes of Sussex and Cornwall," by J. S. Enys ("Philosophical Magazine," May, 1832).

‡ See "Researches on the Influence of Magnetism and Voltaic Electricity on Crystallization and other Conditions of Matters." By Robert Hunt. ("Memoirs of the Geological Survey," vol. ii. 1846).

mineral lodes. De la Beche draws attention to many examples of schistose structure produced by cleavage lamination, where it coincides with the great planes of deposit.* It will be right now to consider the bearing of this on the production of mineral veins. There are *constants*, relating especially to the directions of the mineral veins, which should be clearly understood. These are distinguished as of two well-marked sets, one set holding an eastern and western course, and the other a northerly or southerly direction varying from due east and west to 25° south of west and north of east.

There appears to be considerable probability in the hypothesis that the richness of a vein in metallic ores is regulated by the direction which it takes in relation to the magnetic meridian.

A careful examination of the maps of the Geological Survey of the United Kingdom will prove that the main lines of dislocation extending across the country indicate the operation of two sets of forces, or waves of disturbance, one of them producing a series of fissures in the rocks, having a general direction of north of east, and south of west, and another set operating at varying angles from these.

The production of true planes is scarcely possible under the varying conditions, as it regards hardness of the rocks. In the rending of them, by whatever cause produced, the opening of the fissure will run irregularly, according as the rock presents harder or softer channels. It is not often that any fissure presents a perfectly straight line, as it will generally traverse the rock with more or less irregularity, as if it had been subjected to some mechanical force acting unequally at different times. The following quotation from the Report on the Geology of Devon and Cornwall, is so much to the point that we quote it in its entirety.

"The walls of a fault or a mineral vein are seldom parallel to each other for any considerable distance, and could not well be so except in cases where the fissure has been a mere opening in the containing rock, the relative position of the sides being otherwise unchanged as regards each other, for it can scarcely be supposed that the fracture of rocks, particularly when in beds of unequal hardness, would be such as to produce perfect planes, which if slid in any direction upon each other would still be parallel. On the contrary, the walls are generally found to be very irregular, which must be the case if two irregular sides of a fissure were slid upon each other, no matter in what direction, so that they be uneven, as will be readily seen by

Fig. 41.

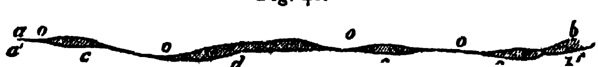


Fig. 42

Fig. 43.

the annexed sketch. Let *a b*, Fig. 41, be a line of fracture traversing a rock or rocks, and let *a b*, Fig. 42, represent the same line; now, if we cut a piece of paper representing this line, and slide part of the cut paper from *a* to *a'*, and from *b* to *b'*, so that the one side be pressed together at the points *o o o o o*,

* "Report on the Geology of Cornwall, Devon," &c. 1839.

we obtain an irregular aperture at *d*, and isolated cavities at *c c c*, and when we compare such figures with nature, we find that, with certain modifications, they represent the interior of faults and mineral veins. If, instead of sliding the cut paper to the right hand, we move the lower part towards the left, about the same distance that it was previously slid to the right, we obtain considerable variation in the cavities so produced, two long irregular open spaces *c c*, Fig. 43, being then formed. This will serve to show to what slight circumstances considerable variations in the character of an opening between the unevenly fractured surfaces of a fissure may be due, such surfaces being moved upon each other so as to have numerous points of contact. The fractures would of course be more complicated among rocks than those above sketched, the irregularities of the sides being in all directions, and it being highly improbable that fragments of the shattered sides, of various dimensions, were not interposed between them, while others fell forwards into the fissures, producing a complication of cavities."

In relation to the enlargement of fissures, after they are once formed, it should be remembered that all fissures, however small, are channels through which water circulates, that the water contains salts in solution, and that these crystallise out in obedience to influence of some *surface force* manifested on each face of the crack. The power of a minute crystal is almost irresistible, and slowly, silently, but certainly, with enormous force, it presses the sides asunder, and by enlarging the fissure gives space for the exertion of a still greater force. Those who desire to deal more especially with the filling of mineral veins will find this force will especially claim their attention. The direction of many lodes in the vicinity of Tavistock and Callington is upon points which do not vary considerably from east and west; those which differ from that line being probably the Crowndale and Gunnislake lodes, and the Wheal Franco lode, near Horrabridge. Wheal Friendship lode differs but a few degrees from east and west; this is also the case with Wheal Jewell tin lode. The lodes on Plaster Down, near Monk's Hill, at Wheal Robert on Roborough Down, Morwell Down, on the banks of the Tamar, above New Bridge, at Holmbush, at Wheal St. Vincent, Wheal Brothers, and at several of the mines around Callington, differ only a few degrees from east and west. On Dartmoor, some two lodes near Okehampton, on both sides of Longstone Hill, appear to take course about west 30° south and east 30° north. Between Belstone and Okehampton the lodes are generally east and west. The Bottle Hill lodes near Plympton vary but little from east and west.

At the Beer Alston mines are two great lead lodes, very argentiferous in character, which are north and south lodes. These may indeed be considered as cross courses, and they take directions which would cut the Drake's Wall and adjacent lodes. The north-north-east and south-south-west lead lode at Redmore Mine, near Callington, is another instance of cross courses bearing lead ore in this district.

Similar conditions are preserved generally in the St. Austell district. The main lodes in the Fowey Consols mines approximate a true east and west direction; but there are minor lodes which run more west-north-west and east-south-east, which direction obtains in the Charlestown, Pembroke,

and the Crinnis mines. The great mass of mineral veins in the Gwennap, Redruth, and Camborne districts may be regarded as a portion of the same system. It is evident that the west-south-west and east-north-east direction is continued from Camborne, through the parish of Gwinnear and Wheal Alfred: the Herland mine, and the lodes of Relistian preserve this direction, as do also the lodes at Wheal Trenwith and St. Ives Consols. Proceeding along the coast from St. Ives to Morvah, nearly all the lodes coincide with the same direction, and those of Ding Dong tin mine in Gulval generally take the same course.

In the St. Just district the lodes have a main direction from the north of west to the south of east, and a remarkable change is observed in the character of the copper ore raised; the St. Just mines yielding, as a rule, the grey sulphide of copper.

Length of Veins.—Lodes vary very considerably in length; in some cases they are only a few fathoms long, and they have been known to extend for two or three miles, several mines being worked on the same lode. "It ought to be noticed that the most experienced miner never satisfactorily witnessed the termination of a vein either on the east or west" (*Phillips*). This is, in many instances, doubtless true, but it cannot be admitted to be so in all cases. This authority has given a plan of the Herland mines and of Prince George mine. In these we find the following are the lengths represented:—

Prince George vein	175 fathoms.
Prince George south vein	225 „
South Branch vein in Herland	250 „
Middle Branch vein in Herland	225 „

the main lodes in these mines traversing the rocks to a far greater length. He remarks that "the veins of those mines did not terminate as represented on the plan, but continued both east and west to an unknown extent, in strings so very small as only to be just perceptible."

Mineral lodes are supposed to extend frequently to considerable distances; but the observations made have from various causes been too general, and too imperfect to be of any real value. Those which are laid down on the maps of the Geological Survey may be regarded as the most reliable, and from those maps the following examples have been selected. First, in the St. Agnes District, the distances have been well established.

At *Wheal Kitty*, lodes are traced from Trevellas to the coast at Tubby's Point, about 3 miles.

The *Polbrean* lode extends from Dirty-Pool, in the centre of the parish, to Chapel Porth, about 2 miles.

Wheal Butson is traced from that mine through *North Towan* and *United Hills*, about 4 miles.

In Breage, near Helston, the *Wheal Vor* lode is rather more than 1½ mile. The actual length of the workings is 1,150 fathoms, and the lode has been traced beyond them.

In the important Gwennap mining district—

North Downs is traced on the Geological Survey Map about				3 miles.
Wheal Busy	„	„	„	2½ „
Treleigh mine	„	„	„	2 „
Poldice	„	„	„	2½ „

United mines, from Chicasse to *Ting Tang* and the Carn Marth Granite, 4½ miles.

In the Redruth and Camborne district:

From *Wheal Fortune* to North Roskeare the lode has been traced 1½ mile.

Cook's Kitchen, from Burncoose to Camborne, 2½ miles.

Dolcoath—which probably is the same lode as is worked in the mines on the north edge of Carn Brea—about 3 miles.

North Roskeare and other mines show distances varying from ½ mile to 2 miles.

In the district of Liskeard, the *South Caradon* lode has been worked for 1½ mile, and *Trevenen* mine, irregularly, for about 2½ miles.

By far the largest number of tin and copper lodes are under a mile in length, as will be seen by reference to the map of mineral veins and cross courses in the Camborne and Illogan district.

The following statement of the lengths to which mineral veins have been traced is given on the authority of Mr. Carne *:—

The old lode in the United mines has been traced from Camborne, through Carn-Kye, to Baldue, a distance of 7 miles. (It appears to the author very questionable if this is a continuous fissure. The ground has been walked over, and there are probable evidences that three lodes follow closely upon each other in very nearly the same direction.)

Wheal Fortune and *Wheal Virgin* lode has been seen for almost 3 miles in length. *Wheal Damsel* and *Wheal Maid* lode, 2 miles. *Wheal Gorland*, *Wheal Unity*, and *Creegbraus* lode, 2 miles.

Wheal Nancy, *Camborne Vean*, *Wheal Stray-park*, *Dolcoath*, and *Cook's Kitchen*, 3 miles. Mr. Carne adds in a note to this: "This lode is so disordered by *cross courses* at Cook's Kitchen *as not to be accurately traced* eastwards. Many miners, however, consider it as the same lode that passes through Wheals Fanny, Druid, and Wheal Sparnon, from whence its course is through Carn Marth Hill to Wheal Damsel, Carharach, and Wheal Maid. This would be nearly 6 miles." The continuity of the same mineral vein is, however, exceedingly problematical.

Wheal Towan has been traced for 1½ mile. *Binner Downs*, *Wheal Sarah*, *Wheal Abraham*, *Oatfield*, *Crenver*, and *Trenoweth*, 2 miles. *West Wheal Fortune*, *Kestal*, and *Penberthy Crofts*, 3 miles. The *Old Wheal Alfred* lode is said to extend 1 mile; but several workings stretch westward, which may be upon portions of the same lode.

None of the tin lodes have been followed more than two miles in length, and those of Wheals Peevor and Poldice are the only ones which have been traced to so great a distance.

It will be seen from this, that the length of the fissures which have been formed, by some great movement of the superficial strata of the Earth's crust, is very variable. If we reflect on the causes which produce those cracks, we can well understand that this would be the case. We have great *cross courses* and *faults* extending across large tracts of country but with these

* "On the Relative Age of the Veins of Cornwall." By Joseph Carne. ("Transactions of the Geological Society of Cornwall," vol. ii. 1822.)

we are not dealing, but with the smaller systems of fissures which belong especially to the series of true mineral veins.

Having considered the evidences which we possess, and which give some idea of the lengths to which mineral veins may be expected to be prolonged, we have to consider *the direction* in which those lodes traverse, which has, according to many excellent observers, an important bearing on the mineral character of the veins. Then we have to examine *the dip* or *inclination* of those ore-fissures, which is very various, and the connection of these phenomena with the bearing character of the lode.

Mr. Henwood, in his prolonged Mineralogical survey—extending over

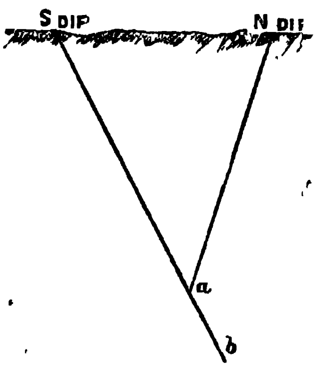


Fig. 44.

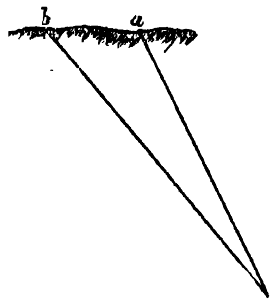


Fig. 45.

several years—made observations in the most important of the mines in the West of England, accumulating a large series of facts of the utmost value, and which are unique of their kind. The annexed list has been derived entirely from this source.*

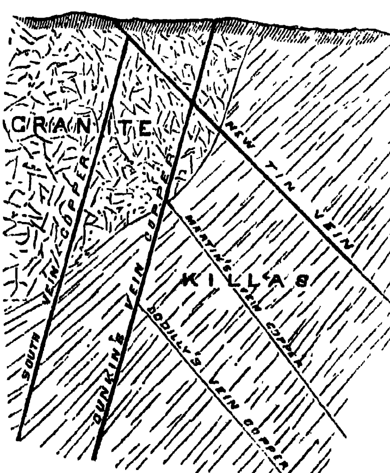


Fig. 46.

Underlie of the Lode.—Mineral veins are seldom perfectly perpendicular; they usually incline more or less to the north or south; this inclination is called the *underlie of the lode.*

When two metalliferous veins underlie in opposite directions, one inclining or having what is called the dip to the north, and the other south, as in Fig. 44, they are generally found to be poor at the junction *a*, and after it at *b*.

When two lodes underlie in the same direction, but that one, *a*, of them dips more rapidly than the other, *b*, it is generally found that, when *a* overtakes *b*, as in Fig. 45, they mutually enrich each other.

Veins are sometimes found to divide in the downward direction, and so

* "On the Metalliferous Deposits of Cornwall and Devonshire." By William Jory Henwood, F.R.S. ("Transactions of the Royal Geological Society of Cornwall," vol. v.)

make branches forming distinct lodes, having an opposite underlie, as in the annexed example, a section in *Tin Croft* mine (Fig. 46).

DIRECTION AND DIP OF LODES.

ST. JUST.

Name of Mine.	Name of Lode.	Direction.	Dip.	Principal Contents of Lode.
Wheal Bellon .	Wheal Whidden .	43° N. of W.	N.E. 83°	Quartz, oxide of tin.
„ Cunning	Main Lode . . .	35° W. of N.	N.E. 73°	Pink felspar, oxide of tin.
„ Edward .	„ „ . .	35° W. of N.	N.E. 80°	Iron ore, copper.
Park-Noweth .	Capt. Ben. Davy's	30° N. of W.	S.W. 67°	Quartz, iron, oxide of tin.
Botallack . . .	Crowns	20° W. of N.	E. 74°	Iron ore, quartz, copper, tin.
Wheal Cook .	Tolven	24° W. of N.	S.W. 68°	Pyrites, copper.
Levant . . .	Main Lode . . .	18° W. of N.	E. 78°	Quartz, iron ore, copper.
	Wheal Shop . .	20° W. of N.	W. 83°	Iron, quartz, copper.
Wheal Sparnon.	Great Work . .	33° W. of N.	S.W. 74°	Quartz, iron, tin.
Boscaswell . .	Main Lode . . .	24° W. of N.	E. 84°	Quartz, iron, oxide of tin.
Balleswidden .		30° N. of W.	S. 60° to 80°	Felspar, quartz, oxide of tin.

MADRON, SAINT IVES, GULVAL, LELANT.

Name of Mine.	Name of Lode.	Direction.	Dip.	Principal Contents of Lode.
Ding Dong .	Bossiliack . . .	30° S. of W.	S. 72° to 80°	Split into branches, schorl and oxide of tin.
	Bussa Trawn . .	33° W. of N.	W. 52°	Iron ore, oxide of tin.
United Mines .	Main Lode . . .	35° W. of S.	N.W. 70°	Quartz, schorl, tin.
„ .	*North Course* . .	40° W. of N.	N.W. 60°	Quartz, oxide of tin.
Wheal Union .	Gwen's Lode . .	15° S. of W.	S. 86°	„ „ „
Wheal Trenwith	Main Lode . .	23° S. of W.	S. 68°	Iron, vitreous and black copper.
Wheal Reeth .	North Lode . .	24° S. of W.	N. 70°	Granite and oxide of tin.
St. Ives Consols	Standard Lode .	25° S. of W.	N. 78°	Iron pyrites, oxide of tin.
Lelant Consols .	Main Lode . . .	40° S. of W.	N.W. 78°	Felspar, oxide of tin.
Providence . .		40° S. of W.	S.E. 66°	Copper and tin.

MARAZION, GWINNEAR, &c

Name of Mine.	Name of Lode.	Direction.	Dip.	Principal Contents of Lode.
Wheal Darlington .	West Mine . . .	20° N. of W.	S.W. 54°	Quartz, copper, tin.
Gwallon	South Lode . .	5° S. of W.	S. 72°	Quartz, oxide of copper and tin.
Rosepeath . . .	Main Lode . . .	5° S. of W.	N. 78°	Iron and copper pyrites.
Great Wheal Fortune	.. ..	E. and W.	S. 64°	Quartz, copper pyrites.
Retallack . . .		22° S. of W.	N. 68°	„ „
Godolphin West .		25° S. of W.	S. 59°	Iron ore, copper.
Herland	North Herland	20° S. of W.	S. 72°	Iron, quartz, copper pyrites.
Relistian	North Lode .	20° S. of W.	N. 64°	Iron, copper pyrites.
Binner Downs . .	Gooseberry .	25° N. of W.	S. 70°	
Wheal Strawberry.	„	25° N. of W.	S. 79°	„ „
Carside	Carside Lode . .	9° S. of W.	S. 70°	Oxide, tin, copper.

HELSTONE, BREAGE, WENDRON.

Name of Mine.	Name of Lode.	Direction.	Dip.	Principal Contents of Lode.
Great Work	Wheal Breage . .	30° W. of S.	W. 68°	Quartz, oxide of tin.
Wheal Vor	Main Lode . . .	28° S. of W.	N. 65°	Iron pyrites, tin.
„	Wheal Wreath. .	28° S. of W.	N. 74°	„ „
Polladras .	Engine Lode . .	35° S. of W.	N. 64°	Quartz and oxide of tin.
Trumpet .	Wheal Ann Lode	22° S. of W.	N. 78°	Iron ore, oxide of tin.

CAMBORNE AND ILLOGAN.

Name of Mine.	Name of Lode.	Direction.	Dip.	Principal Contents of Lode.
Stray Park	North Lode . .	N.E. and S.W.	S.E. 78°	Quartz, iron, copper pyrites.
Dolcoath .	Entral	30° S. of W.	N. 64°	Copper, galena, silver.
	Harriet's Lode . .	N.E. and S.W.	S.E. 70°	Quartz, copper pyrites.
	Caunter	11° N. of W.	S. 70°	„ „
Cook's Kitchen .	South Lode. . .	22° S. of W.	S. 65°	Quartz, copper, tin.
„ „ .	Dunkin's Lode .	34° S. of W.	S. 60°	Iron ore „ „
Carn Brea . . .	Teague's . . .	28° S. of W.	N. 78°	Copper ore, tin.
„ „ . . .	North Lode . .	30° S. of W.	N. 70°	„ „
South Roskear . .	Main Lode . . .	32° S. of W.	S. 80°	Iron and copper pyrites.
North Roskear . .	N. Roskear Lode.	32° S. of W.	N. 77°	Copper and iron pyrites.
Wheal Crofty . .	North Lode . .	5° S. of W.	N. 73°	„ „
East Crofty . .	Longclose . . .	15° S. of W.	N. 80°	Quartz, copper pyrites.
East Pool . .	South Lode . .	25° S. of W.	S. 70°	„ „
„ „ . .	North Lode . . .	40° S. of W.	N. 68°	Copper and iron pyrites.

REDRUTH AND GWENNAP.

Name of Mine.	Name of Lode.	Direction.	Dip.	Principal Contents of Lode.
Wheal Buller . .	South Lode . .	25° S. of W.	N. 64°	Iron and copper pyrites.
Tresavean . . .	Main Lode . . .	30° S. of W.	S. 78° and 84°	Iron, copper pyrites.
Ting Tang . . .	,, ,, . . .	12° S. of W.	N. 70°	,, ,,
United Mines . .	Old Lode . . .	27° S. of W.	N. 60°	,, ,,
,, ,, . .	Buzza or Mundic .	25° S. of W.	N. 70°	Quartz and copper pyrites.
Consolidated Mines	Taylor's Lode . .	27° S. of W.	N. 76°	,, ,,
,, . .	Deebles	30° S. of W.	N. 70°	Copper pyrites and black.
Damsel East . .	North Lode . .	17° S. of W.	N. 72°	,, ,,
Cardrew	South Lode . .	17° S. of W.	N. 60°	Iron and copper pyrites.
North Downs . .	John's	21° S. of W.	N. 72°	Iron ore and pyrites.
,, ,, . .	Main Lode . . .	14° S. of W.	S. 82°	Iron, copper, blende.
		ST. AGNES AND PERRANZABULA.		
Charlotte East	Main Lode .	12° S. of W.	S. 64°	Iron, black copper.
Polbwroe .	Pye Lode .	30° S. of W.	N. 45°	Quartz, oxide of tin.
Pink West .	Tin Lode .	25° S. of W.	N. 48°	Tin, iron, copper.
,, ,, .	Lead Lode .	20° W. of S.	E. 68°	Quartz, galena.
Wheal Kitty	Bottle Lode	35° S. of W.	N. 85°	Oxide of tin, copper pyrites.
Wheal Prudence	North Lode	35° S. of W.	N. 76°	Copper and blende.
Great St. George	South Lode.	5° S. of W.	S. 50°	Quartz, copper.
Wheal Budnic .	Lead Lode .	36° S. of W.	N.W. 70°	Oxide of tin and galena.
		ST. AUSTELL DISTRICT.		
Dowgas . . .	Trewithen .	S.E. and N.W.	N.E 68°	Quartz, copper pyrites.
Polgooth . . .	St. Martin's	8° S. of W.	N. 45°	Quartz, oxide of tin.
Charlestown . .	Tin Lode .	35° N. of W.	N.E. 55°	,, ,,
Pembroke . .	Main Lode .	8° S. of W.	N. 74°	Quartz, copper.
East Crennis .	South Lode.	10° S. of W.	N. 72°	,, ,,
Fowey Consols .	Bone's Lode	4° N. of W.	N. 64°	Iron and copper pyrites.
	Jeffrey's . .	6° S. of W.	N. 72°	,, ,,
Beam	North Lode	16° W. of S.	N.W. 60°	Felspar, clay, tin.
		CALLINGTON.		
Redmoor West	Main Lode . .	15° S. of W.	N. 50°	Iron pyrites.
Redmoor . . .	Johnson's Lode	10° N. of W.	S. 68°	Iron and copper pyrites.
,, . . .	Lead Lode . .	8° E. of N.	W. 60°	Clay and galena.
Wheal Brothers	Main Lode . .	24° S. of W.	S. 42°	Galena, blende silver.
		DEVONSHIRE.		
Wheal Frances . .	Main Lode	25 S. of W.	N. 45°	Copper, oxide of tin.
Wheal Robert . .	Ore Lode	20 S. of W.	N. 70°.	Quartz, pyrites.
Wheal Friendship .	Main Lode	E. and W.	N. 58.	Quartz, copper, and tin.
Wheal Betsy . .		4 W. of N.	W. 74°	Quartz, galena.
Birch Tor . . .		20 W. of S.	W. 72°	Quartz, oxide of tin.

In this list it will be seen that the direction of the mines in St. Just is—8 are from 20° to 35° west of north, and 3 are from 30° to 45° north of west. In the St. Ives district 9 mines run from 15° to 40° south of west, and 2 are respectively 33° and 40° west of north. In the Marazion district we have 1 lode, due east and west, 8 mines vary in direction from 5° south of west to 25°, and 3 are from 20° to 25° north of west. In the Helstone district 3 mines are from 22° to 35° south of west, and 1 is 30° west of south. In the Camborne district all the lodes run south of west, as they do also in the Redruth district. In St. Agnes 7 mines vary from 5° south of west to 35°, and 1 only is 20° west of south. In the St. Austell district there are 4 mines in which the lodes run a few degrees south of west, 2 are from 4° to 35° north of west, and 1 south-east and north-west. Around Callington 2 lodes run south of west, one 8° to the east of north, and one 10° north of west.

While in Devonshire this list gives 2 mines south of west, 1 east and west 1 west of north, and 1 west of south.

The *breadth* of the mineral veins varies considerably. It will be seen by the following table that the tin and copper lodes vary from each other in this respect. The character of the rock, its hardness or softness, its toughness, or its liability to fissure, has an important bearing on the size of the vein.

	TIN LODES.			COPPER LODES.			
Districts.	Less than 00 fathoms deep.	In Granite.	In Slate.	Less than 100 fathoms deep.	In Granite.	In Slate.	General average.
	Feet	Feet	Feet.	Feet.	Feet.	Feet.	Feet.
St. Just . .	1·81	1·86	2·0 *	2·22	1·12	1·58	2·23
St. Ives . .	1·63	1·55	—	1·45	1·25	1·22	1·61
Marazion . .	9·0*		9·0 *	2·93	—	2·93	4·68
Gwinnear, &c.				1·5	—	2·11	2·9
Camborne, &c.				3·4	3·3	—	3·68
Helston . .	1·86	1·18	3·51	2·4	2·57	3·51	2·86
Redruth, &c.	—		—	3·2	3·5	3·56	3·36
St. Agnes .	1·47*		1·17*	3·55	2·45	2·74	3·09
St. Austell .	7·21	5·19	4·06*	3·08	2·68	3·2	4·79
Tavistock, &c.	2·0*	2·0	2·0*	9·4	6·57	7·0	6·9 †

Mr. Carne says: "The breadth of tin lodes are exceedingly various; their width varies from that of a barleycorn to 36 feet." In a note he informs us that the lode in Relistian mine is of that width for 20 fathoms only, and that in Nangiles the tin lode in some parts is 30 feet wide. Mr. Henwood gives the following as the sizes or breadths of the lodes:—

	Least size.	Extreme breadth.
Tincroft, *Highburrow Lode*	3 or 4 feet	or 30 or 40 feet
North Roskear ,,	1·5 foot	,, 18 feet
Wheal Vor ,,	3 feet	,, 30 ,,
Polladras Downs, *Bar Lode*	1 inch	,, 4 ,,
Polgooth, *St. Martin's Lode*	1 foot	,, 42 ,,
Pembroke ,,	½ inches	,, 40 ,,

Mr. Henwood, whose observations were more extensive than those of any other man, shows that the average breadth of lodes, of less than 100 fathoms deep, is 3·97 feet, whilst below 100 fathoms the mean size is but 3·36 feet. The *lodes* in Granite are somewhat *smaller* than those in Slate (this is doubtless due to the Granite being the hardest, toughest, and least yielding rock), and tin ore is more abundant in the Granite than in the Slate. The lodes, however, which yield the ores of both tin and copper in a state of mixture are considerably *larger* than those in which either of them is singly found. The lodes in which both these ores together occur average a breadth of 4·7 feet. This greater average breadth takes place, whatever may be the nature of the containing rock, or the depth at which the mean may have been estimated. Is this due to crystallogenic force?

The depths to which the Cornish mines have been worked are very various, depending of course on the value of the lodes which the miners have been exploring. The depths of a few of the more important mines are

* These are from single examples only.
† In these averages the sizes of lodes at a greater depth than 100 fathoms are included.

given in the following table. It is an important element in considering the problem of metalliferous veins:—

Tresavean (former workings)	350 fathoms.
Clifford Amalgamated, The; or, Consolidated mines	372 ,,
Dolcoath (perpendicular depth, 365 fathoms—2,190 feet; *perpendicular* from surface—deepest level, 364 fathoms under the *adit*. Engine shaft, 8½ fathoms under the 364 level)	401 ,,
Cook's Kitchen	345 ,,
Carn Brea	315 ,,
East Pool	210 ,,
Wheal Vor (to adit 35 fathoms) *under adit*	330 ,,
South Wheal Francis	223 ,,
Botallack (from sea-level—worked under the sea 2,448 feet)	250 ,,
Wheal Agar	222 ,,
South Wheal Crofty	210 ,,
South Caradon, Liskeard	275 ,,
DEVONSHIRE.	
Devon Great Consols, deepest shaft	300 ,,
Wheal Friendship, Tavistock	240 ,,
Bedford United	148 ,,
Wheal Crebor	130 ,,

CUMBERLAND, ETC.—The lead mines in the North of England are usually worked by tunnels driven into the hill,—at its lowest point,—and then the mineral lode is followed up into the hill or worked "upon the rise."

These tunnels or levels are remarkable works. The Nentforth Level is the longest in Alston Moor; it extends nearly seven miles. The portion between Haggs vein and the town of Alston is an underground canal, and from Haggs vein to Rampgill vein, it is used as an ordinary level about 180 feet above the canal. Rampgill Level extends from the Nent River to the boundary between Cumberland and Northumberland, and is rather more than a mile long.

The Dowgang Level extends for nearly two miles. Brownley Hill is a mile and a half long, and is ramified through the whole extent of the Brownley Hill veins. The Browngill mines, all the Nenthead mines, and others adjoining, are connected by levels. A distance, as the crow flies, of about seven miles has been tunnelled to effect this.

Rampgill vein is the *deepest* in Alston—120 fathoms. More than three-fourths of the lead produced in this district has been found in the 150-*feet* section in which it generally occurs—the principal portion in a section of 12 feet of Little Limestone and the 48-feet of Great Limestone.

In NORTH WALES very few of the mines go deeper than about 600 feet.

In CARDIGANSHIRE about 160 fathoms, or 960 feet, may be regarded as the average depth.

ISLE OF MAN.—The lead and zinc mines of this district are deeper.

Great Laxey, from surface	265 fathoms.
North Laxey ,,	136 ,,
Foxdale ,,	155 ,,
East Foxdale ,,	105 ,,

These statements are derived from the best authorities, and they fairly show the average depth to which our metalliferous mines have been worked.

It has been stated by many authors that veins become smaller as they become deeper—that they are indeed wedge-shaped. Others have asserted the contrary. Neither of those statements can be maintained as a general rule.

Wheal Abraham, in Cornwall—when it was working—was considerably larger at the depth of 240 fathoms than it was at the surface. At Dolcoath mine the lode was largest at the depth of about 80 fathoms. Wheal Alfred lode was much larger at the depth of 110 fathoms than at any less depth, but at 150 fathoms it decreased in size. Wheal Neptune lode was 9 feet wide at surface, and it was the same width at the depth of 120 fathoms.

YORKSHIRE (*Teesdale*).—The mining tracts of Teesdale, Swaledale, Wharfdale, and Greenhow Hill are considerably disturbed. Professor Sedgwick traces a great *fault* as ranging down Teesdale. Limedale is on the line of a dislocation, Swaledale is nearly parallel to the Old Gang and other east and west lead veins. A small fault passes down Wensleydale—a remarkable dislocation ranges east and west along the head waters of the Nid, and a great depression about Pateley Bridge alters its course afterwards to the south-east.

Professor Sedgwick also noticed this fault from Egglestone by Lowton, as far as the *High Force*. It is remarkable as a general and leading fact with respect to *mineral veins*, and by consequence to the *faults* which almost universally accompany them in this district, that their prevailing direction is north of east. The *greatest number* of mineral veins occurs in this direction. The greatest *quantity* of metallic ores is obtained from veins running east and west. "This, indeed, is a general fact, for east and west courses of veins are the normal directions for the greater part of Europe, whatever be the age and nature of the rock including them" (*Phillips*). Westgarth Forster says: "The fissure-veins of the mines in Cumberland and Durham mostly extend from east and west, or more properly, one end of the vein points west by south while the other tends east by north, although there are other veins running nearly north and south, commonly called *cross veins*; and it must be remarked that these cross veins have been rarely found so productive of metallic ores as the others, excepting when the right running veins and the cross veins intersect, in which case the cross veins generally carry ore for some distance from the place of intersection, but very seldom in any other stratum than Limestone, and especially in the Great Limestone of Alston Moor."

Near Mallam, south of Wensleydale, it is in the Lower Scar Limestone principally that the lead mines of Greenhow, Nidderdale, Grassington, Kettlewell, Arncliffe, Hardflask, and Ingleborough are, or were, worked; but to the north of Wensleydale the Cam Limestones become the most productive. In the mining districts of Greenhow, Grassington, and Kettlewell veins yield ore both in the Limestone and Millstone Grit series. Veins have been found more or less productive in the *Millstone Grit* south of Lothersdale, about Greenhow Hill, Grassington, Buckden Pike, near Leyburn, and in the line of the Old Gang vein in Swaledale and Arkendale. Mines are worked in the Whin-Sill at several points north of Maize-beck.

The Cononley lead mine exhibited a curious deposition of sulphide of lead in a bed of Coal Measure shale. Calamine and white oxide of zinc occur in considerable quantities in Yorkshire, chiefly or wholly in the *Lower Scar Limestone*, as in Bolland, near Whitewell.

Upon those features Professor John Phillips founded the following remarks: "From these facts it follows that the dependence of particular metallic

products on *particular series of rocks is principally a local phenomenon without general application*; but on more minute analysis of the phenomenon it is found that, in a given district, certain beds generally *are* and others generally *are not* productive of metallic treasures. It has been attempted, from facts such as these, imperfectly understood, to draw a conclusion in favour of a close and necessary dependence between the produce of a vein and the chemical character of the containing rocks, so as to permit an inference that the vein itself was *segregated* from the opposite rocks, or else that the whole is of *contemporaneous* origin.*

Most veins in the mining district of Alston preserve a tolerably direct course, often, it is said, for several miles. They are commonly called *veins, cross veins*, and *quarter-point veins.* The first named are often called *right-running veins*, and have a direction or bearing which is generally nearly east and west, sometimes slightly varying from that to a north-east and south-west direction. The cross veins are those which have a bearing nearly north and south. There are a few veins which have an intermediate bearing; these are the *quarter-point veins.* The "point" of a vein is the usual phrase to designate its bearing.

If three east and west veins lie near each other, the middle one is simply designated by its particular name; as, for example, *Hudgill Burn Vein.* The vein north of this is called *Hudgill Burn North vein*, and that to the south *Hudgill Burn Sun vein. Sun*, in the mining phraseology of the northern mining district, is invariably used for *south.* If more veins be nearly parallel, they are sometimes—as at Hudgill Burn—denominated *Second Sun vein* or *Third Sun vein.* Cross veins, when near together, are distinguished by the names *East* and *West Cross veins.*

In this district the names of the same veins vary in different parts. Sir John's vein, Stoweray vein, Scar-end vein, Leehouse Well vein, for example, are one continuous cross vein. These names are generally limited to what is called a *lease length*, which is usually about 1,200 yards.

The veins may be classified into three distinct kinds. The first class being the so-called east and west lodes, their direction, however, varying between north 60° east and south 63° east, magnetic.

The second class comprehends the veins running in a north and south direction. These veins vary less than the east and west veins. In the strata above the Great Limestone they seldom contain any metallic substances. Much lead ore has been produced from them *in* the Great Limestone, and both lead and *copper* ores in the strata beneath it.

The third class form a set of small veins which intersect the above-named veins. They traverse the country in two directions—south 55° east, and south 55° west, magnetic. They contain little mineral matter in the strata above the Great Limestone. In the underlying strata they are filled with copper and iron pyrites and earthy minerals, but very seldom contain lead ore either in the Limestone or the Sandstone rocks. It has been observed that those veins having a south-easterly bearing are more numerous than the others, but they are generally poor, or, as the miner expresses it, "weak."

* "Illustrations of the Geology of Yorkshire." By John Phillips, F.R.S. 1835.

The *Great Sulphur vein* of Alston Moor, which has a main general direction from the north-west to the south-east from Burnhope Seat to Cashburn Force varies in its mineral character in various localities. At Cashburn it is chiefly filled with roughly crystallised quartz. Between Cashburn and Crossgill where the direction of the vein is indicated by a series of low rounded hills, it consists of quartzose minerals which have resisted the decomposing influences of atmospheric agency. At Crossgill it contains, disseminated through the quartz, iron pyrites, which is slightly *auriferous*. Many weaker strings occur here, and these contain copper pyrites, but not in sufficient quantity to prove profitable. On the top of Noonstones, where this vein is at its widest, it is entirely filled with quartz. At the Tyne River it contains less quartz, and that of an impure nature. At Darngill Bridge the sulphur vein does not vary much in character from the strong east and west veins of the district. There is but little quartz, and the vein is filled with "*douk*,"* where *plate* or *shale* forms its sides. No mining works have been made to prove any of the east and west veins which intersect this great vein.

Browngill and Bentyfield veins are the most important of the east and west veins of Alston Moor. The Bentyfield vein splits into strings on the south side of Rodderup Fell vein; and at Dryburn those strings are collected and form a vein of considerable size. A dislocation of not less than 60 feet occurs at this point.

Several other veins besides those just noticed are thrown off Browngill vein. Briggle Burn is by far the strongest of these. This vein increases its width and throw as it approaches Carr's vein. After its intersection with this cross vein it is divided into two parts, respectively termed Rampgill and Scaleburn veins. The direction of the Coal Cleugh east and west vein is nearly parallel to the anticlinal axis. In the Nenthead mines Rampgill vein displaces the strata about 18 feet, in the Coal Cleugh district about 36 feet. On the north side of Bentyfield Old Carr's cross vein, in Alston Moor, is *weakest* at the north end, and increases in strength *northwards*. This large vein throws up the strata—

At Middle Cleugh Second Sun vein	42 feet
At Middle Cleugh vein	48 "
At Carr's vein	60 "
At Broomsberry	72 "
At Nentsberry Green	162 "

Sopwith, who gives these measurements, writes: "It is easy to imagine how, when the strata were separated by the formation of veins (*i.e.* by a breaking of the rocks forming a fissure), some portions should sink or others be raised from the level they occupied before; but it is not so easy to account for the fact that, however great may be the vertical disruption of the strata, no trace of it appears on the surface; for when the strata are removed a distance of 100 or 200 feet, it would be reasonable to suppose that some lofty precipice on the surface would betoken the mighty rent."

The difficulty of accounting for this is not really so great as Sopwith thinks. In the accompanying figure a dislocation—*a downthrow*—of the strata is represented of 50 feet. The first appearance would be the formation of a

* *Douk*, or *Douke*, is a soft substance derived from the shale forming the walls of lodes.

cliff, A, Fig. 47; but in the process of time, by atmospheric action, or by denudation by rains, there would be a wearing away of the cliff A to a line drawn to (*a*), and there would be a piling up of the débris at (*b*) so as to completely hide the rent at the surface.

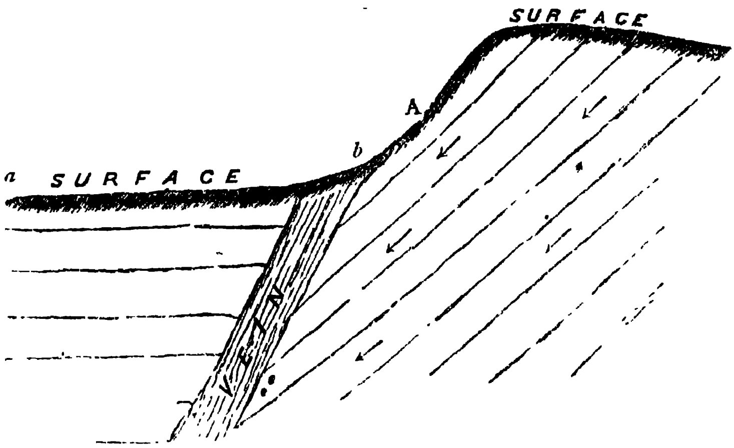


Fig. 47.

It is not intended to introduce any close examination of this remarkable mineral district. A few remarks, borrowed from Mr. Wallace, on the "Formation and Direction of Mineral Veins," will convey a sufficiently clear explanation of the phenomena of mineral direction:—

"The Copper Dyke heads and Fletcheras veins are also formed from weak strings, and on the west side of the Tyne traverse the district in a parallel direction. On the east side of the Tyne all these veins are deflected in a more northerly direction. Except Brownley Hill vein, they cease to exist before reaching the east boundary of the Alston Manor. Near Garrigill Burn cross vein Black Dyke vein comes into existence, and traverses the district near to and parallel with Fletcheras vein."

It will have been noticed that in this quotation from the work of a practical miner the veins are spoken of as if they were active agents in producing the dislocations and disturbances of the strata. It is necessary, before we continue the quotation, that it should be intimated that experience and observation carry conviction to the mind that the fissures are in all cases the result of disturbances of the Earth's surface prior to the filling in of those cracks. After giving numerous examples of "throws," which are of but little practical value, our author proceeds:—

"Rodderup Fell vein throws up the north cheek about 18 feet. It is displaced in a longitudinal direction at the West cross vein, with this exception, its bearing between Shield waters and Black Ashgill cross vein is very direct. At How Hill, on the east side of the Tyne River, a strong portion bears off in a more northerly direction, and wastes into very small portions, or leads, as it approaches Flough Edge vein. Flough Edge and Nattrass Redgrove veins traverse the district in a direction parallel to Browngill vein, and from Redgrove vein a number of east and west veins split off the north side in a somewhat similar manner; with one or two exceptions, all these dwindle to

nothing in their course eastward. The direction of Bayle Hill and Fistas Roke vein is nearly parallel to Rodderup Fell vein; both are of small magnitude. In the Blaygill mine the latter is moderately wide, but only dislocates the strata about 3 feet. Thorngill veins traverse the district in the same direction as the Browngill veins. These veins possess considerable strength. They enter into combination, and, as Lough vein in Blaygill mine, dislocate the strata not less than 24 feet. The direction of the Slote vein does not vary greatly from that of the Thorngill veins. . . . . In Alston Moor the east and west veins generally throw up the south cheek, and hade, dip, or strike in a contrary direction.

"We shall now endeavour to prove," says Mr. Wallace, "that their existence and direction are due to the tension to which the strata were subjected when thrown out of their horizontal position.

"In tracing this connection we shall begin with the Browngill fissures. Excepting the great sulphur vein, these are of much greater magnitude than any other east and west veins in the district. To whatever phenomena veins may be related in causation, the connection will be most clearly seen where the greatest amount of effect is produced. At the point where the two anticlinal axes join in Kilhope, and at the point where Rodderup Fell vein is intersected by the West cross vein, near Shield waters, the beds are elevated to the same horizontal position. Between these two points is the general bearing of the great Browngill line of fissures, consequently this series of veins traverses the district on the level line of the strata; or, in other words, it traverses the district nearly at right angles to the general strike of the beds on the south side of the fissure. . . . .

"Again, from the intersection of the axes of elevation in the Kilhope district, the beds rise in the direction of the east and west axis, and culminate between Burnhope Seat and Dongreen, or the source of the Tyne River; from thence, in its north-westward direction to Cross Fell smelt-mill, they incline considerably. Now, in their direction from east to west, the magnitude and throw of the Browngill fissures vary in the same or a corresponding manner. This vein, or fissure, exists in its greatest magnitude precisely opposite the point where the strata are most elevated on the line of the axis, and in proportion as the strata incline in each direction from this highest point of elevation, so do the magnitude and throw of Browngill vein diminish.

"The Browngill fissures are not only the greatest in magnitude but also in extent of those having a similar direction in Alston Moor. In the Nenthead district the Briggleburn veins traverse on a level line with the strata. In the Coal Cleugh district the beds incline a little in the direction of the veins eastward, and, as they approach the Swinhope district, their direction is not parallel to the axis. Next to Browngill, Fletcheras vein is the strongest of its class in Alston Moor.

"Except Crag Green Sun vein, which terminates at Old Grove's veins, no veins are thrown off on the north side of Fletcheras vein. The other east and west veins of Alston Moor are related to the same phenomena as Browngill and Fletcheras veins, and are dependent on the same laws of causation, and were formed contemporaneously with them. Their magnitude is proportional to the intensity of the elevating forces, as denoted by the effect upon the

strata, and their direction varies as the dip, or, to speak more forcibly, *their magnitude and direction are proportional to the amount of twisting or wrenching undergone by the strata, when their horizontality was disturbed by subterranean forces, either of elevation or depression.*"

Cross Veins.—In Alston Moor the veins bearing north and south, usually in the district called Cross Veins, generally traverse those which are termed right-running veins, which pursue a point nearly east and west. The celebrated Werner* laid down the rule "that every vein which *intersects* another is *newer* than the one traversed, and is of later formation than those which *it traverses*; of course the oldest vein is traversed by all those that are of a posterior formation, and the newer veins always cross those that are *older*." In applying this rule it is necessary to determine the *intersected* and the *intersecting* vein, which is not always easy. Werner again says: "When two veins cross, one of them without suffering any derangement or interruption, traverses the other, this last is interrupted and cut across through its whole thickness by the former. The first of these is said to traverse the other, and the latter to be traversed by the latter."

Westgarth Forster observes, that in Alston Moor the veins bearing north and south traverse the east and west veins, and he infers, therefore, that the cross veins are the most recent. Professor Phillips, speaking of the metalliferous veins, and of the great lines of disturbance, observes "that the numerous faults of an ordinary character are evidently related to and dependent upon them. It appears possible, certainly, to distinguish two periods of disturbance: one, *the older one*, being marked by an east and west direction—these are essentially the most important mineral veins—and the other by a north and south direction, being generally whin-dykes and some few mineral veins."

In the strata above the Great Limestone, the lodes contain but few sparry minerals, the cross veins in this respect differing considerably from the east and west veins. In some parts of the cross vein, large masses of metalliferous minerals are found, while in others but little removed from them blue clay alone is discovered. The mineral contents of the cross veins in Alston Moor are generally softer and less compact than the contents of the east and west veins. The cross veins may therefore be considered as a marked class, distinguished in many ways from those which take an easterly and westerly direction.

The following are the most important Cross Veins which traverse the Alston Moor and Coal Cleugh district.

The Coal Cleugh east cross vein. *The Coal Cleugh* west cross vein.

Pump Sump Cross Vein.—This is supposed to be identical with the Longhole lead vein of the Kilhope district.

The Bounder End cross vein dislocates the strata but very little. On each side near its intersection with Rampgill vein, extensive flats of lead ore have been found.

Rampgill and *Scaleburn* are found farther west in the Nenthead district. In its course northward the Rampgill vein combines with the cross veins which traverse the rocks of Alston Moor, on the east side of the Nent River.

* "New Theory of the Formation of Veins," chap. iii. sec. 31.

Carr's vein and *Wellgill cross vein* are found in the Haggs mine.

Black Ashgill—on the north side of Capel Cleugh veins—is of considerable magnitude. On the north side of Dowgany veins it is ramified into several portions. Between the Grassfield and Hudgill Burn mines it is a vein of moderate strength, divided into two branches. Northward from Hudgill Burn it gradually diminishes in width and throw. In Foxeshield mine it is found in two portions, of but little importance. On the north side of Blaygill Burn it diminishes to a mere string.

Where the Black Ashgill vein intersects with the Dowgany veins two weak veins are formed, one passing through the Hudgill Burn lead mine, the other crossing the Nent River, and ceasing to exist.

Garrigill Burn—or Old Groves—is the next cross vein of any importance.

Windshaw Bridge is another cross vein, whose direction corresponds with the course of the Tyne River.

Sir John's cross vein is on the south side of the Great Sulphur vein. It is split into two portions on the north side of Crossgill, and becomes very wide at the point of intersection with Rodderup Fell vein in the Slaggy Burn mine. Like some of the Nenthead cross veins, by inclining to each other, these dislocated sections must become one vein at no very great depth below the surface.

Rodderup Fell cross vein has not been found on the south-west side of the Great Sulphur vein.

Some weak cross veins intersect Crossfell vein near the Smelt Mill, and these are probably identical with the Nether Hearth Cross vein.

These cross veins are evidently of a different age in Alston Moor from the east and west veins. The east and west veins are usually found intersected by the cross, or north and south veins. Mr. Wallace endeavours to establish the following proposition: "The cross veins in the mining district of Alston Moor were formed either anterior to or contemporaneously with the veins which traverse the district in an east and west direction." After examining with much care all the conditions observable in the mining districts of Alston Moor, this observer remarks: "We are now in a position to affirm that the cross veins, as well as the east and west veins, were in existence soon after the close of the Coal Measure period and before the formation of the lower Permian rocks. The Magnesian Limestone rests unconformably upon the former, and the ninety-fathom dyke passes underneath the latter without dislocating its beds."

The Quarter-point Veins.—This class of veins is generally of very small magnitude, and the disturbance produced by these fissures is but of a few inches.

In the northern part of the district, the strongest of these veins is the Rampgill *second sun vein* in the Nenthead mines. For 180 fathoms Rampgill vein traverses the district in the direction of the quarter-point vein.

In the lower part of the district, veins of this class appear to be much stronger. There is one in Rodderup Fell mine bearing a north-east and south-west direction, which throws the north-west side up about 40 feet. This vein is parallel with several dykes or veins of considerable magnitude found in the old collieries situated at Gilderdale Head.

The veins of large throws in *Swaledale* are generally cross veins, and have a direction north and south, or north-west and south-west. The cross veins of large throws are usually unproductive. When productive it is generally in the Limestone. The east and west veins of large throws, when productive of lead ore, are frequently so through the whole strata.

In looking through a large number of sections of the strata it becomes evident that the most productive portions of the vein are those which have Limestone beds on either side, and really these sections afford but very slight support to the view that the metalliferous deposit is to any considerable extent regulated by the physical differences in the enclosing beds. All the productive lodes are found between the "crow lime" and the "underset Limestone" in this district.

The Crystalline Rider is composed of such substances—not being lead ore—as are found in the vein, as calcareous spar, fluor-spar, carbonate and sulphate of baryta, silica, iron pyrites, oxides of zinc, and the like.

The *Sedimentary Rider* consists of any friable or tenacious earthy substances found in mineral veins, as *whamp* or *vamp*, *donk* or *douk*, or *platy* sample.

"The primary rider is so termed because it is the broken portion of the bed or beds thrown in between the sides, cheeks, or walls of the vein, and consequently its origin was contemporary with the vein itself. In the secondary riders we have the growth of all crystalline and metalliferous (mineral ?) substances; and in the tertiary we have the general filling up of the vein with sedimentary deposits chiefly from the disintegrated portions of the strata."*

Limestones and *Cherts* are regarded as the *most productive deposits* in the northern mines, but we have not seen any reason assigned for this. *Grits* and *Plates* are, as already stated, considered as *unproductive deposits*, but no good examination of the causes regulating this has been made.

The directions of veins in Swaledale are as follows: Those of small throws have a general bearing of west and south-west, to east and north-east, and these are stated to be the most productive of lead ore, from having ore-bearing beds, on each side of the vein nearly opposite to each other.

As a general rule, lead and iron lodes run either north and south or north-north-west and south-south-east, the copper lodes east and west, in the *Keswick*, or *the Lake District*.

The direction given is the *true bearing*; the miners using *magnetic bearings*; so that a lode coursing magnetically north and south has, geographically, a course of about 20° west of north.

The Keswick United Silver Lead Mines, Thornthwaite Lodes.—The Thornthwaite lode *hades* east, is sometimes 20 feet wide, and very gossany at the top. With the galena there is much blende, and some carbonate of lead occurs. This in nearly all cases is due to the infiltration of water containing much carbonic acid in solution. *Rachel Wood lodes, Beckstone vein*, and the *Ladstock lodes* have not been worked for many years. *Glenderaterra Lodes.*—

* "An Inquiry into the Deposition of Lead Ore in the Mineral Veins of Swaledale, Yorkshire." By Lonsdale Bradley, F.G.S. 1862. A considerable amount of useful information has been collected and recorded in this volume with special reference to this district.

The oldest workings on these lodes date back about sixty years. They are a little south of Roughton Gill. A small lode was opened upon in 1872, but the work has been abandoned. *Blencathera lead vein*, called *Saddleback*, lies twelve fathoms east of the shaft, and was worked about fifteen years since. In the Lonscale crags on the west side of the valley are several strings which fall into the lode and render them productive. Blende in considerable quantity exists in this lode. Curious deposits of brown and red iron ore have been formed in the level within the last twenty years. These beds are, of course, the result of oxide of iron precipitating from the percolating water. Wood End lode and Gate Gill are found to change their *hade* considerably, and appear to yield best where the inclination is least.

The *Loweswater Lodes* were worked nearly forty years since, and a considerable quantity of lead extracted from them. Several small workings have been carried on within the last half-century. *Newland's Vale Lodes.*—These are *Sealby's lode* and *Scope End lode.* Never very productive. The *Castlebrook Lode.*—This lode hades east and courses very nearly north and south. In connection with it is another lode, sometimes called *Francis lode*, containing very rich-looking lead ore in a crumbling quartz.

The *Yewthwaite lode* runs north-north-west and south-south-east, hading to the north-east at an angle of 75°. Carbonate of lead and a good deal of blende have been found in this lode. The *Barrow lode* is a continuation of the Yewthwaite. This lode greatly resembles the Thornthwaite, only occasionally yielding good bunches of lead ore. The *Stonycroft lode* joins the Yewthwaite and Barrow. It was worked twenty years since. Around Rowley End are evidences of many old workings, but nothing is known ot them. The *Brandelhow lode* has the usual north-north-east and south-south-west course, *hading* east. The lowest workings in this mine were at 50 fathoms; none were carried for a greater distance than 1,500 feet from the lake, measured along the lode. A saline spring occurs in Brandelhow mine, which is taken medicinally by the country people. It contains much chloride of sodium and some sulphate of magnesia.

Three veins have been worked known as the *Helvellyn lodes*, in the Wythburn lead mines. The *Old Vein* and the *Blue Rock*, the former hading east and the latter south, yield lead, much of it argentiferous. These lodes, from the difficulty of working them through the Serpentiferous dykes, have never been successfully worked.

The *Greenside* mine is the richest in the county. Its general course is but a few points west of north, and its hade is east. The width varies considerably, there being sometimes strings of ore through a breadth of 40 feet.

In *Grisedale Valley* are three lodes, the workings upon which are very old, but apparently unprofitable. The *Eagle Crag vein*, with an east and west course, hading a little to the south, but nearly perpendicular, has been recently opened, but has not proved productive. The *Ruthwaite Lodge* or *Tongue Vein.*—The workings here are mostly old, but of late very little has been done. *Hartsop lode* has been worked upon in ancient days, and yielded a little lead and some blende.

WALES.—The importance of several of the districts of Wales indicate the advantage of considering them in the next place.

Nearly all the productive mineral veins in the counties of Cardigan and Montgomery have a strike east-north-east and west-south-west. Goginan Darren, Cwm-symlog, Logaulas, and many other large and productive deposits, agree within a few degrees of this course. Tre-Taliessin, which returned considerable quantities of lead ore, runs north-west and south-east At Cwm-ystwith the main lode points east-north-east, while the "*comet*" lode courses west-north-west. Many of the lodes to the east of the Rheidol show a northerly turn, and on the outskirts of the main metalliferous districts several small lodes yielding ore conform with the direction of the meridian as Pant Mawr and Siglenlas on the south-east, Rhysgog on the south, and others on the north.

The "underlie," or inclination of the lodes, is most frequently to the south, but there is much irregularity in this. At Esgair-Hir, Darren, and Delife the underlie is to the north—the variation being between 60° and 80° from the horizontal. The filling matter of the mineral vein is principally slate—in angular fragments of all sizes, from small particles intimately mixed with the lead ore, to large masses, which frequently appear to divide the lode. This clearly establishes the fact that those veins are rents or fissures formed by convulsions, the lines of these cracks showing the direction in which the wave of disturbance has moved. *Quartz* is usually associated with the lead ore in all these veins. The hard and massive silicious matter which forms irregular veins in the Slate is not regarded as a favourable indication, whereas the cellular, granular, and powdery spar is looked on by the lead-miners as promising for ore.

Calcareous spar occurs in many of the lead lodes. It is often found in veins, and sometimes of considerable size. In the bed of the Ystwith is a vein of calc-spar ten feet in width. At Henfwlch Mr. Smyth says it is met with in large ribs, and encloses small quantities of copper, lead, and zinc ores. Similar appearances are evident at Esgair-Hir. In Montgomeryshire calc-spar is also abundant.

Sulphate of Baryta occurs near Llanidloes, in a vein at Cwm Mawr, and at Llangynnog. Carbonate of Baryta (*Witherite*) is associated with large masses of lead ore at Pen-y-Clyn, and in some other mines it is found in the veins.

Fluor-Spar, so commonly found in the mines of the North of England, is scarcely known in the lead mines of this district.

Galena (sulphide of lead) is the usual metallic ore of Cardiganshire and Montgomeryshire. Most of it contains silver, often up to the proportion of 75 oz. to the ton of lead. White lead is found in a few lodes particularly near the surface, evidently formed by the action of water holding in solution carbonic acid. This carbonate is sometimes found at considerable depths, but only where there has been a long-continued flow of water through the galena of the lode.

The Phosphate of Lead (Green lead ore, *pyromorphite*) is found tinging the lead ore—but only where it has been exposed to the action of water containing decomposing organic matter.

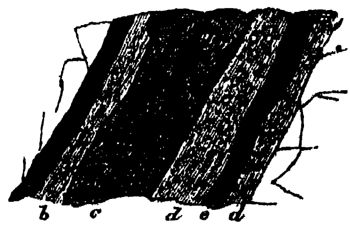
Zinc ore (*black jack*) is found, but not on the whole so abundantly as the galena. It occurs frequently in thin strings and small patches in the poorer

lead veins. There are but a few mines in which it is found in sufficient quantities to pay for mining and dressing, at the low prices which have prevailed for several years. Calamine, the silicious species of zinc ore, has been found at Nant-y-Creiau, but it has not been worked for some time.

Copper ores are not found to any extent in this district. Copper pyrites have been worked at Tre'rddol, and this ore exists of a fine quality in Cwm Ricket, near Llanidloes, in the bed of the Severn.

Iron Pyrites, brown iron ore, and manganese ores are found in various parts of the county, and they have been occasionally mined.

Studying the phenomena presented by the mineral veins of Cardiganshire, we find but little to establish the views which have been promulgated in reference to the deposits of metalliferous minerals in other districts. There is but little regularity in the deposits of the lodes. "Generally," says Mr. W. W. Smyth,* "we may observe that calc-spar takes the inner side of the quartz,—whether in drusy cavities or in ribs,—and it would appear that the galena occupies an analogous position with regard to the zinc, a point of great importance as bearing on the theory of these mineral veins and its future application to mining."



Lead Lodes in Cardiganshire.

Fig. 48.—*a*, zinc blende; *b*, galena; *c*, quartz. | Fig. 49.—*a*, copper; *b*, quartz; *c*, zinc blende; *d*, pyrites; *e*, galena.

The annexed diagrams (Figs. 48 and 49) are sections of two lodes. The one is at Nant-y-Creiau and the other at Tyn-y-fron. It is not often that we are enabled in the lodes of Cardiganshire to refer to this banded structure, as showing that the deposits in the fissure took place at different times. Generally the lodes are *brecciated* masses of angular fragments of Slate rock, cemented by mineral matter. Observations on the lodes of Cardiganshire and Montgomeryshire do not prove that the ore-bearing character of the lode has any relation to the direction, nor is it satisfactorily shown that there is any connection of productiveness with the dip of the veins. When two lodes approach each other at a small angle the junction is usually marked by a larger deposit of ore, and when branches or smaller veins fall into the main lode, whether on the line of strike or on the dip, the vein is enriched. Where veins have combined it is commonly found that a large mass of lead ore has been found. The returns of lead ore raised in this county show a considerable falling off.

The lead veins of Cardiganshire do not vary—as do the lodes of Cornwall and elsewhere—when they pass from a harder to a softer rock. The vein and the rock through which the lode passes are frequently found to be of the same

* "On the Mining Districts of Cardiganshire and Montgomeryshire," By Warington W. Smyth. ("Memoirs of the Geological Survey of Great Britain," vol. ii. part 2.)

character. "The rock, as in all the Goginan districts, is so solid that its bedding would be indistinguishable but for the stripes of a darker colour which here and there relieve its pale grey tint; but where the lode passes into the 'cross measures'—as they are termed—of Slate, not a vestige of ore remains to tempt the miner onward" (*Smyth*).

FLINTSHIRE VEINS.—*The Holywell Group.*—The mineral veins generally take two principal directions, the one nearly east and west, the other north and south. The east and west lodes are the most metalliferous. The north and south are often quite unproductive, and are seldom rich, except in the neighbourhood of the east and west lodes.

In the case of the intersection of two lodes of different systems, if one is heaved it is the east and west which is heaved by the north and south. The north and south lodes are also known under the name of "*cross courses.*"

In a case where—as in the district of Holywell—shale is met with above the chert, the miners stop the work when they come in contact with the shale.

These rules have been adopted from all antiquity by the Welsh miners in every mine. The particular manner in which the old works were carried out, serves to guide the managers of the mines, and the agents acting under their orders, in their search for mineral deposits and in prosecuting their excavations. The mine of Holywell Level comprises the great east and west lode of Holway and numerous cross courses. Old workings have been conducted in some east and west lodes, but these are less important, and situated to the north of the main lode, which extends over a length of three miles following a general direction of west 5° north. In the neighbourhood of the Victoria shaft it is nearly west 15° north, east 15° south, as indicated in the following rise made in the 140-yard level:—

Indications of the Compass.		Successive Distances between the Points of Observation.
	To the East.	
$123\frac{1}{2}°$		46 yds. 6 in.
124°		34 „ 6 „
123°		29 „ 3 „
135°		47 „ 4 „
$138\frac{1}{2}°$		63 „ 7 „
$126\frac{1}{2}°$		42 „ 3 „
	To the West.	
304°		55 „ 0 „

Admitting 20° for the actual declination, and taking 125° for the mean direction, we shall have $125° - 20° - 90° = 15°$.

The underlie is towards the north, and in the deep part it is regular and at 9 inches per yard $= \frac{1}{4}$; in the upper part it is very variable, and presents in the chert a series of steps.

The cross courses are directed north 25° to 0° east; their inclination (always very great) is for the most part to the east, but sometimes to the west.

The works have been pushed to a depth of 150 yards; a long adit level, at a distance of 61 yards from the mouth of the Victoria shaft, carries the water from the Holywell into the valley and takes it as far as the town.

The ancients, who had followed the north and south lode in the black Limestone, were stopped by meeting with a schistose rock; although the lode became thin at once, the trace of it could still be distinguished. However, fearing they should meet with a shale formation, they abandoned the

works. The actual manager, suspecting their error, pushed the gallery on some yards, and again came upon the lode in the chert; and the lode, after having been reduced to less than an inch, became again 2 feet in width.

The north and south lodes in the mine of Holway are less important under all circumstances than the main lode east and west.

In following the level, the intersections can be clearly traced. Generally the north and south lodes cross it without any deviation. Sometimes, by chance, the north and south lodes in the chert are heaved two or three yards; and considering the weakness of the cross courses, relatively to that of the great east and west lodes, and to the nature of the rock, these heaves have nothing characteristic. The north and south lodes, of which some incline to the west and others to the east, appear to re-unite after obtaining some depth. The rock beds dip north-north-east. At the roof of the lode in the upper part of the mine a shale is found, which is black and solid enough to sustain itself in a horizontal position sometimes for a space of ten yards.

Chert, generally black, takes, in productive regions, a bluish tint, often very clear, and with a translucent appearance quite characteristic. This is known by the miners under the name of *bearing chert.*

The blue *chert* is represented by beds of bluish schists, such as are met with in the cross course; while the black is characterised by an argillaceous Limestone, perfectly black, and having crystalline veins impregnated with liquid bitumen. The white chert is of a very pale grey-yellow.

The ore from the east and west lodes is almost exclusively a sparry carbonate of lime, containing veins of galena and blende.

The spar is generally white, and formed of crystals pressed together in a confused mass. However, *geodes* are sometimes found containing crystals more clearly defined, not only of spar, but also of galena. They have been discovered at a depth of 10 or 12 feet, of 1½ foot in width and 5 feet in length, in the direction of the lode. Near the ore the spar takes the pale tint, much prized by miners, who call it *bearing spar.* In the north and south lodes the ore is still principally in the spar, but with a large proportion of yellow clay. This clay forms the bed of the lode, and often also the intermediate beds in the spar. Fragments detached from the sides are frequently found embedded in the white spar.

The clay which abounds in the north and south lodes is also met with, but in less quantity, in the east and west lodes, the ore of which is poor.

Galena is, as at Holway, more earthy in the cross courses and more laminated in the east and west lodes. There is very little blende, and it is only met with in the east and west lodes.

Carbonate of lead is found in considerable quantities in all the lodes, and some calamine, with this peculiarity, that the carbonate of lead lies principally in the east and west lodes, and that the calamine seems altogether absent in the chert.

In a cross course of 20 inches, at a distance of 8 yards from a north and south vein which bears the mineral, lead, copper pyrites, and blue and green carbonate of copper are found.

The direction of the main lode in the Maes-y-Safn mine is west 24° north, east 24° south. To the west a string branch is also worked,

The vein inclines towards the north; towards the west the inclination is 75°, to the east it is not more than 50°—in 1,200 yards. The cross courses, north 7° west and south 7° east, which are not numerous, are completely barren, and contain only carbonate of lime and clay: they bring into the mine an enormous quantity of water, which, in spite of an adit at a depth of 100 yards, is very difficult to get rid of.

The works have been pushed to a distance of 250 yards in the white Limestone, above which lies a certain thickness of Aberthaw lime. The beds tend towards the south-east; they are covered to the east by Sandstone. At Maes-y-Safn, galena is found, and a little blende—which is considered a bad augury for the richness of the lode—which carries neither calamine nor fluor-spar.

The lode is seen cropping out on the surface, causing a fault in the Limestone. The ancients have made very deep excavations at the foot of the escarpment which it has formed. The Sandstone advances through the Limestone chain to the south of Maes-y-Safn, about three-quarters of a mile, forming an elevated and almost barren plateau, which inclines a little east of south. It is in this region that the rich mines of Bwlly and Jamaica were discovered.

ANGLESEA.—Having dealt with the rocks of this island in their relation to the mineral lodes, it only remains to direct attention to some conditions which are more closely related to the questions treated of in this chapter. Sir A. C. Ramsay* suggests that the alteration of the strata of Parys mountain was effected deep underground, probably under the influence of heat and moisture, the altered strata having since been exposed by denudation. The fracturing of the country by *faults*, he thinks, is of a much later date than this early metamorphism, and the cross *faults* and *copper lodes* of the mountain belong to that later period, but running, as the great original deposition of copper pyrites did, in the line of the strike of the slaty band between the hard rocky masses. He also thinks it is by no means certain that the ore may not have been introduced in solution into the *strata*, some of which helped to produce the metamorphism of the large hard rock band, and which seems to have impregnated the original sediment with an extra amount of silica.

Mr. Henwood† informs us that he found numerous examples of copper pyrites and vitreous copper ore dispersed in irregular and unconnected masses, and in minute veins, through the Slate in Parys mountain. The termination of these veins is abrupt; they are lost without any intervention of joints or cross veins, and they reapper within the distance of a few fathoms.

ISLE OF MAN.—The principal mines of the Isle of Man are Laxey, Foxdale, and Brada Head. These lie in the *Grauwacke* formation, with the exception of the small-grained Granite, which exists at Foxdale. The direction of the vein at Laxey is west-south-west and east-north-east, and at Brada Head there is but little deviation from that direction; the inclination of the lead lode at Laxey and Foxdale, with respect to the horizon, is two yards in six.

* "The Geology of North Wales." By Sir A. C. Ramsay, LL.D., F.R.S. ("Memoirs of the Geological Survey." 1881.)

† "The Metalliferous Deposits of Cornwall and Devon." By William Jory Henwood, F.R.S. 1843.

At *Laxey* mine the galena is very pure, its specific gravity being 7·652. The Bishop of Llandaff states that the produce of silver was 20 oz. to the ton, but it has occasionally risen so high as 35 oz. In connection with the galena, carbonate of lead and fibrous carbonate of copper are occasionally found. The walls of the vein are formed of a fibrous, silky Grauwacke, with lamellar crystals of calc-spar and pieces of bitterspath, the *rider* or vein-stone being a breccia composed of grauwacke, quartz, bitterspath, and brown blende.

At *Foxdale* the lead ore has a specific gravity of 6·095. The vein is filled with blue and white chalcedony, galena, and some iron pyrites. Sparry iron ore in large lamellar crystals of a dark colour is also found in the lode, the galena adhering to it; grauwacke forms the south *cheek* or side of the vein.

Brada Head gives a less pure variety of galena, its specific gravity being 6·622 — the vein-stone or *rider* being a yellowish quartz, enclosing iron pyrites.

Wolfram has been occasionally found in the Isle of Man, but rarely in any useful quantity.

The name *Tinn-wald*, at St. John's Chapel, has sometimes led to the idea that tin existed in the island. According to Dr. Berger, tinn-wald is a Danish word—*tiny*, a court of justice, and *wald*, fenced. The court was held on an artificial Mount near the middle of the island. It will be curious to trace if any relation exists between this Mount and Crockern-Tor on Dartmoor, as both have been courts of justice for mining cases.

The following statement has been obtained from Mr. Kitto of the Foxdale mines, than whom no one is better informed on the question of the Isle of Man mineral lodes :—

"I think I am quite right in saying that the *general direction* of the north and south lodes is from 8° to 12° east of north, with an eastern underlie of 2 feet in the fathom. This refers to the Laxey, Snaefell, and Bradda lodes. The Ballacorkish lode is also north and south with a western underlie of two feet per fathom.

"In this district of Foxdale the principal lodes run 8° south of east, with a south underlie of 2 feet per fathom. We have traced them in our Foxdale mines for over 3 miles in length, during which they have been intersected by several oblique veins, and also by at least three north and south veins, all of which have a western underlie of about 2 feet. In our western mine, known as 'Beckwith's,' the 'Wardells,' north and south, cross the main east and west lodes; and two miles farther east, lodes known as 'Old Foxdale,' 'The Mayhies,' north and south—and the 'Flappy,' north and south—cross the main or east and west lodes. All of those north and south lodes have yielded silver lead ore, but not in such quantities as the east and west lodes. The 'Cornelly' lodes, which are about one mile north from Foxdale, have the same direction, viz. 8° south of east, but their dip or underlie varies considerably, still it is south.

"I need hardly say that in 'Old Foxdale' we are now permanently down into the Granite, and we have passed through a 'floor' of Granite at 'Cornelly' (now Townshends), about 30 fathoms thick, but into the Slate again. All the other mines on the island are in the Slate. The depths of

the mines belonging to this company now at work are—Old Foxdale, 200 fathoms below adit; Mayhies, 84 fathoms below adit; Townshends or Cornelly, 125 fathoms below adit; Great Laxey, 259 fathoms below adit; Snaefell is 130 fathoms from surface; Bradda, 70 fathoms from surface; Ballacorkish, 60 fathoms below adit. In the Great Laxey the main lode and some others of the north and south lodes underlie *eastward.*

"Personally, I do not like to see a north and south lode in the Isle of Man 'carry its head' to the west of north; neither do I like an east and west lode to 'carry its head' to the north of east."

IRELAND.—In the Limestones of the counties of Cork and Limerick, *argentiferous galena, copper ore, blende,* and *iron pyrites* are found. In the townland of Cloghatrida, which lies a little to the west of Stoneville, there is a *lode* which contains all those minerals in a gangue of calc-spar and rotten ferruginous Dolomite. The lode runs nearly east and west, and underlies north at 70°. In the line of the strike of this lode the same ores were found, and to the south-east of the railway a lode bearing about north 45° east.

Near St. Crohan's hermitage on the Coomakista ridge, between Lough Currane and Westcove, in Kerry, a quartz vein was found bearing east 10° north underlying north-north-west at about 80°. This vein or lode was traced for a distance of nearly two miles, but it varies much in size and has not always the same underlie. Sir Richard Griffiths, in his list of Irish mines, names, as a locality for lead, a spot east-north-east of Milltown. A lode was examined here having a dip to the south-south-east at about 60°. In Ross Island a mine producing copper was worked; and Raspe, in 1761, reported on a lead mine in Cahernane Demesne, Killarney.

SCOTLAND.—Williams notices that mineral veins are liable in some districts in Scotland to be "thrown off their level by slips. When a streek vein is thrown up or down, out of its ordinary course and level by one of the *rake* or *slip* veins, if the *slip* happens to be tolerably wide and to contain more or less of ore, or of other promising mineral soil, the miners will follow the rake vein up or down, whichever way it has thrown the *streek,* until they meet with it again, and then they will work one or both of them as they approve or appears worth while; but on the contrary, if the slip or rake vein happens to be a close switch in that place, and thus the two sides are close and cemented together. In that case there is the more danger, as some of those slips which throw the strata and flat veins a great many fathoms up or down are so close and imperceptible that the flat veins may be lost without the utmost attention. . . . When the vein is cut off by the *slip* and thrown off its former level, the miners meet firm stone in the face instead of the new vein; and when they touch this stone, if they are perfect in the history of the strata above and below these veins, and recognise the stone which meets them in the face, they can then make a near guess how far the vein is thrown off its former level. If it is a down slip, the vein will be *cut off first above*; but on the contrary, if it be an *up slip,* it will be cut off first below, and there will always be some small vestige, although it should be no more than a close joint, to show which way the ore is gone."

CHAPTER III.

THE LAWS RELATING TO MINERAL DEPOSITS.

THE result of training—that is, of instructing men in a knowledge of such sciences as bear upon mining—is very strikingly exemplified in the number of Saxon philosophers, and miners, from whom we have derived most of our theories—perhaps it would be safer to call them hypotheses—which relate to the formation of veins or lodes. Werner says: "Agricola, Rösler, Henkel, Hoffman, Oppel, Charpentier, and Trebra have furnished all the information we possess on the subject. Nor is this surprising, when we reflect that it is chiefly the philosophers and miners of Saxony who have formed the art of mining into a distinct branch of science, and who have carried their researches on this subject to the greatest length, and created some of the accessory sciences,—as the chemistry of smelting ores and subterranean geometry."

Becher, who wrote in 1669, ascribes the formation of metals and minerals to certain subterranean vapours which, arising from the bowels of the Earth and penetrating the veins, produce a peculiar change.*

Balthasar Rösler, who was mine-master at Altenburg, died in 1673. It was not until 1700 that, at Dresden, his "Speculum Metallurgiæ Politissimum," folio, was published, promulgating views which were to some extent adopted by Werner.

Stahl, the German chemist—one of the most remarkable of men—followed Becher in many respects. He concludes, however, by setting aside Becher's theory, and considers veins, as well as the substances of which they are composed, as having been formed at the same time with the Earth itself, and, of course, as being of the same age with the rocks in which they occur.†

Henkel attributes the formation of the contents of veins to a peculiar exhalation produced and engendered by a fermentation, supposed by him to take place in the interior of rocks. The basis of each metal and mineral he supposes to exist already in the substance of the rock, and that by a peculiar process of nature it is matured and converted into metal. Henkel clings to a few of the alchemical hypotheses: for example, he speaks of "subtile earths;" again, of mercurial, arsenical, and sulphureous parts.‡

Hoffman, born at Leipsic in 1741, was appointed Assessor to the Council of Mines at Freyberg, and after Henkel's death he delivered lectures on Mining. Eventually he obtained the rank of commissioner of mines, and

* Joh. Joachim Becheri, "Physica Subterranea." Lipsiæ: 1703. The first edition was published at Frankfort-on-Main in 1669.

† Georg. Ern. Stahlii, "Specimen Becherianum." 8vo. Lipsiæ: 1703.

‡ Joh. Fr. Henkel's "Pyritologia; or, History of Pyrites." Leipsic: 1725. And "Medicorum Chymicorum." Dresden and Leipsic: 1727.

soon afterwards he took charge of the mines of the King of Naples. Hoffman supposed veins to have been formed in the fissures of rocks, which were gradually filled in by the separation of mineral matter from the waters flowing through them.*

Zimmermann was a pupil of Henkel's, and chief commissioner of mines. He says: "Minerals are undoubtedly formed in the rock, but daily experience shows that the rock is not of itself capable of forming a metal, for were the mineralising principle capable of converting it into a mineral we should find whole mountains which had undergone this change; but this change we only meet with in some parts, which follow certain directions, and being thus transformed, constitute veins. The veins, when they have not suffered the entire change, or when they do not contain perfect minerals, are still of a different nature from the rest of the rock. An attentive examination will show that they are of a decomposed and friable nature, appearing to have a tendency to return to their natural earthy state; from which we may conclude that the veins were in reality originally the same as the rock, but that the texture had been altered and decomposed by some particular saline substance which, penetrating the rents and fissures, had rendered them fit to be transformed into minerals. In this way saline substances prepare and render the earthy matters capable of being converted into the matrix of minerals. These same saline substances also assist in the formation of metals. To this we cannot withhold our assent, if we admit, what experience teaches, that all minerals are mixed bodies, consisting of a metal, an earth, and an acid." †

Von Oppel was Captain-General of the mines of Saxony. In his "Subterranean Geometry," published at Dresden in 1749, he writes:—

"By a *vent* is understood an empty fissure or gap in a rock. Vents are generally narrow, mere cracks in the rock.

"A *vein* is a fissure extending a great way through a rock, which it cuts and divides. It is filled with materials different from the rock. *Fissures* and *veins* do not run in the *direction* of *strata* of the rock, they traverse and intersect them.

"A *bed* is a mineral deposit, the nature of which differs from the other beds and layers of the same mountain. It has the same direction as the strata of the mountain." ‡

Von Oppel admits to the full that *veins were formerly fissures open in their superior parts.*

Werner quotes with approval the following passage from Von Oppel's essay on the "Working of Mines":—

"The natural structure of the globe seems to show us that, after the formation of the primitive and principal secondary mountains, they had suffered great desiccation and been exposed to violent shocks. In consequence of these changes the rocks and mountains, which formerly composed one continuous mass, were split asunder. Whilst this took place, it might easily happen that one of the rocks slipped from the other without ceasing to

* Jo. Georg. Hoffmanni, "Dissertatia de Matricibus Metallorum." 4to. Lipsiæ: 1738.
† Carl. Fred. Zimmermann, "Obersachsische Bergakademie." Leipzig: 1749.
‡ "Anleitung zur Markscheide kunst nach ihren anfangs grunden und ausübung kurzlich entworfen." 4to. Dresden: 1749.

touch it, or these parts might be separated from each other, leaving between them open spaces, which were afterwards filled up, in part at least, with different mineral substances. The greater part of these grand events belong to that part of subterranean natural history which can only be elucidated by a consideration of the facts which the Earth presents to our view, for all these great revolutions took place at a period long before the globe became habitable to the human species. But whether fissures and veins were actually formed in the manner we have described or not, it is no less true that this manner of representing their mode of formation and the relative situation which they bear to one another in the mountain is the most simple way of accounting for them. It explains the uniform law of their formation both in a general and more particular manner, and consequently we shall admit it as the real one. This hypothesis would be still more satisfactory to the naturalist, if it were equally easy for him to conceive how a new mineral substance could be formed in these fissures, of a nature different from the rocks in which the veins occur.

"A *rent*, or interruption of the continuity of a rock, when it intersects the strata, is named a *fissure* (gangkluft)."

Werner then remarks that the direction and position of veins may differ more or less from that of the beds of the rock in which they occur. He discusses the problem that mineral substances are of a different nature from those of which the mountain in which they occur is formed.

We find him again treating of the same subject. In continuation he says:—

"It is difficult to conceive how rents and openings of considerable size can be produced without some portion of the adjoining rock suffering such a strain as would form lateral chinks, so that the principal rent should terminate in several smaller ones. When these smaller rents are filled with the same matter as the principal vein, they are said to be branches of the principal vein. In this case the vein is said to ramify or divide into branches. The portion of rock contained between these branches is for the most part of a wedge shape; in such cases the included mass is called a wedge. When the branches run for any length in the same direction with the main trunk they are called *accompanying branches*.

"It sometimes happens that when a vein is formed in a stratified mountain, the vein not only traverses, but also deranges a stratum; that is to say, one of the two parts of the intersected stratum changes its position, being elevated or depressed in relation to the other strata. In this case the strata are said to have shifted; the vein which produces this effect is called (wechsel) *shifter*."

Werner calls this a "luminous, instructive, and satisfactory view;" and he concludes his remarks on Von Oppel by quoting the following geognostic observations, which, he says, "are extremely interesting and useful in practice":—

"In the hollows and valleys of mountains of a moderate height the veins for the most part follow the direction of the valleys.

"When a vein has been cut or deranged by a visible rent it is again met with in following the direction of this last, on the supposition that when the parts of a vein are thus cut they are mostly separated from each other."

Werner then gives the names of Lazarus Erkern and Modestin Feachsen, who have written useful works on the chemistry of the subject and on assaying, and Gellert, who has written a treatise on the same subject. Lower Saxony has produced Cramer, and Sweden Scheffer and Bergman and the Aulic counsellor Gmelin, who have treated the same question very learnedly.

He remarks: "The science of subterranean geometry was formed by Agricola, Rösler, Weidler, and Baier successively; but brought to perfection by Oppel, Kästner, and Sheidhauer. The most recent work on subterranean geometry is that of Professor Lempe."

Lehmann expresses his opinion that *rents* are open fissures, and *veins* are fissures filled in. He says the veins which we find in mines appear to be only the branches and shoots of an immense trunk, which is placed at a prodigious depth in the bowels of the earth; but in consequence of its great depth we have not yet been able to reach the trunk. The large veins are the principal branches, and the slender ones its inferior twigs.* After this Lehmann need not be quoted any further.

Wallerius, who wrote in 1768, had a very imperfect idea of the nature of mineral veins.†

Delius published in 1770 a short treatise on rocks and veins. He considers veins to be rents formed by the drying of the rocks, which have since been filled up. His ideas are mainly borrowed from Agricola.‡

Bergman, in his "Physical Geography," merely says miners apply the name of *vein* to rents that are filled up, and consequently are *shut*—the words *kluft* and *schiœl* express nearly the same thing; but what is called *trum* is a small rent quite shut, whose walls converging form a wedge.§

Von Charpentier published in 1773 his "Mineralogical Geography of Saxony." He objects very strongly to the theory which considers veins to have been rents which have been filled up by mineral substances.‖

Pryce, in 1778,¶ speaks of *lodes* as fissures in rocks occasioned by so many shocks and subsidences, adding "that the strata were not unfooted, shaken, or brought to fall once only, or twice, but several times. He observes also that mechanical effects are produced by *cross courses*: "Because *cross gossans* or *cross flukans* run through all veins of opposite directions, without the least interruption from them, it seems reasonable to conclude that the east and west veins were antecedent to the cross veins."

Baumer,** counsellor of mines, Leipsic, 1799, remarks: "Veins differ from the strata in which they occur both with respect to their form and substance. Their formation is posterior to the rock. It appears from many observations that they have been formed under the ancient sea, for their upper extremity is often covered with several beds of schistus; and in

* D. Joh. Gottl. Lehmann's "Abhandlung von den Metalmüttern und der Erzeugung der metalle." 8vo. Berlin: 1753.

† Joh. Gollsch. Wallerii, "Elementa Metallurgia Speciatim Chemica." Holmiæ: 1768. And "De venis Metallicis."

‡ "Abhandlung von den Ursprunge der Gebirge und der darinne befindlichen Erzadern, oder der sagenanten Gänge und Klüfte; ingleichen von der vererzung der Metalle und insondereit des Goldes." Edited by Professor Schreiber.

§ Sir Torbern Bergman's "Physicalische Beschreibung der Erdkugel." Greiswald: 1791.

‖ Further illustrated in his "Beobachtungen über die Lagerstädte der Erze." Leipzig: 1799.

¶ "Mineralogia Cornubiensis," p. 82.

** Jo. Guil. Baumer, "Fundamenta Geographiæ et Hydrographiæ Subterraneæ." 8vo. Giessæ: 1779.

cavities in the substance of the vein we frequently meet with marine animals in a petrified state."

Gerhard, in his Essay,* supposes veins to have been originally rents in mountains which were afterwards filled up with mineral substances. Many causes may have led to this. Minerals, he supposes, may have originally existed in the rocks, and that they had been carried in a fluid state into the fissures, &c., where we now find them.

Von Trebra is quoted by Werner, but as he deals with *putrefaction* and *fermentation*, as causes of mineral formations, we need only refer thus briefly to him.

Lieutenant Lasius,† in his work on Mountains, considers *veins* as rents in the rocks, which have been filled in by water. He thinks nature has given "minute metallic seeds," which by water have in one place been converted into *lead*, in another into *silver*, or any of the metals or semi-metals.

In 1791, Abraham Gottlob Werner, professor of mineralogy at Freyberg, published his "New Theory of the Formation of Veins, with its Application to the Art of working Mines." This was translated into English in 1809 by Charles Anderson, M.D. His theory of mineral veins has claimed the attention of the thinking miners and men of science. Being a Counsellor of the Mines of Saxony and Professor of Mineralogy, he had remarkable opportunities for the examination of lodes, and the art of working mines at Freyberg. He was evidently a man whose powers of observation were of the highest character, and whose reflective faculties had been trained in a truly philosophical school. It therefore becomes necessary to give more than ordinary attention to his "New Theory of Veins."

In the commencement of his elucidation of his so-called "New Theory," Werner quotes, after a brief allusion to some classic authors, Agricola, who, in his "De Ortu et Causis Subterraneorum," says the *rents* and *fissures* in which veins are found he supposes to have been formed partly at the same time with the rocks themselves, and partly afterwards by the waters penetrating them.

He then refers to Balthasar Räsler (Rösler). In his "Speculum Metallurgiæ" he writes: "A *fissure* is a chink or gap which cuts and divides the rock, and is like the crack in a vessel which allows water to flow through it. Some of these fissures are long and wide, others short and narrow. What constitutes the vein itself, and what it contains enclosed within it and forms its principal part, is either the materials in which the mineral is found, or metallic matter, or a kind of clay, quartz, spar, &c. . . . . The rock sometimes contains *druses*; these are hollow cavities of a round or oblong form and different sizes, which are commonly found in veins. Sometimes the veins are full of these cavities, when they are said to be *open*. A vein is said to be *shut* when it is quite filled up either with stony or metallic matter. The druses are often filled up with clay or other matter. In that case the vein is said to be closed, although it contains druses."

* Carl Abraham Gerhard's "Versuch einer geschichte des Mineral-Reich." Berlin: 1781.

† George Otto Sigismund Lasius, "Beobachtungen über die Harzgebirge, als ein Beitrag zur Mineralogischen Naturkunde." Hanover: 1797.

The "New Theory" starts by giving definitions to two forms of mineral deposits, *Veins* and *Stockwerke.*

Veins are rents which have been formed in mountains, and have been afterwards filled up by mineral matter more or less of the nature of the rocks. The Swedish mineralogists give the name of *gangar* to mineral repositories in general. Veins properly so called they name *skiœlard* (consult "Wallerii Elementa Metallurgiæ").

Stockwerke is a part of a rock of a greater or less extent, which is penetrated and crossed in all directions by an almost innumerable quantity of small veins.

True veins are thought to be originally, and of necessity, rents open in their upper parts, which have been afterwards *filled up from above.* With the causes producing those rents, after what has been already said, we need not embarrass the reader.

Werner supposes the Slate and Sandstone rocks to have been produced by *precipitation*, or in the humid way. If we understand him correctly, he believed that the older rocks were subjected to the influences of air and water, and thus disintegrated to an immense extent.

As the matter which was held suspended in the water, then flowing over the surface, was gradually deposited—precipitated—on the igneous and other rocks of an older age, these old rocks might have been fissured in the process of cooling or drying. Then the mud of the waters would have filled those fissures, and, as Werner thinks, "furnished and produced" the substance of the veins.

Veins have been produced at very different times, and the *relative age* of each can be easily assigned, thus—

(*a.*) Every vein which *intersects* another is *newer* than the vein traversed. "The *oldest vein* is *traversed* by all those that are of a posterior formation, and the *newer veins* always cross those that are *older.*

Werner's own expression is: "By the crossing and intersecting of veins the antiquity or relative age of each can be easily assigned. Every vein which intersects another is newer than the one traversed, and is of later formation than all those which it traverses. This crossing of veins is of great importance, and deserves to be kept in remembrance by all who wish to become acquainted with the study of veins; yet, till lately, it has always escaped the observation of mineralogists."

Sopwith, quoting some "highly intelligent miners" in opposition to this theory, says: "Cross veins I suppose to be fissures which were first formed, and this easily accounts for the shifting of the east and west veins by supposing the force which created these second veins not strong enough to carry them directly through the cross vein, but yet sufficient to continue the fissure in the next weakest place. The Wernerian system seems absurd, because if the east and west veins were first formed it would require the whole strata to be shifted along with them, which alone would carry them off their point; besides which, while one vein is carried off its point northward, another lying near it is removed southward, whereas if a longitudinal shift of the strata occurred at the formation of the cross vein all the other veins would

be removed in one direction. Nor," says Sopwith, "is this general rule of cross veins intersecting east and west veins without exception, as Scaleburn cross vein at Nenthead, in Alston Moor, is carried eighty feet off its point by an east and west vein."

Werner visited the mines of Cornwall with Mr. Carne, who was, therefore, led to a general acceptance of his hypothesis in the following words:—"When two veins cross, one of them, without suffering any derangement or interruption, traverses the other; this last is interrupted and cut across through its whole thickness by the former. The first of these is said to traverse the other, and the latter to be traversed by the former. The vein which crosses another is of newer, whilst the last is of an older formation."

(*b.*) *The middle part of veins* is commonly of later formation than that portion which is nearer their *walls*, and what we find in the *upper part* of a vein is *newer* than what we meet with in the lower part.

(*c.*) In a specimen composed of different minerals the *super-imposed portion* is always of a newer formation than that on which it rests.

Werner, in defining mineral veins, follows Rösler very closely. "The cavities which veins now occupy are, he says, ore rents which have been formed in the rocks; these cavities were at first fissures, gaps, and rents, of various sizes, with openings in their upper parts." In support of this theory he brings forward nine proofs, which are as follows:—

1.—"When the mass of materials of which the rocks were formed by precipitation in the humid way, and which was at first soft and movable, began to sink and dry, fissures must of necessity have been formed, chiefly in those places where mountain chains and high land existed."

2.—"Rents and fissures are still forming from time to time in mountains, which have a close resemblance to those spaces now occupied by veins. The fissures are formed mostly in rainy seasons, or by earthquakes."

3.—"Veins, in respect of their form, situation, and position, bear a strong resemblance to rents and fissures which are formed in rocks and in the Earth; that is to say, both have the same tabular figure, and the deviations which they make from their general direction are few in number and very inconsiderable."

4.—"No one can doubt that the small oblong cavities (gang-klüfte) which are found in great abundance in rocks are in reality small rents or chinks. Now there exists an uninterrupted chain, from the narrowest fissure to the greatest vein, so that it is impossible to draw a line of distinction between what is actually to be considered as a true rent or fissure and that which is a vein without being a fissure. We sometimes meet with a small vein which does not exceed the thickness of a straw completely filled with mineral matter; and at other times we find rents of three or four inches wide, which are perfectly empty."

5.—"Are not druses, and the small crystals which line their walls only certain parts of a vein which have not yet been filled up, and consequently the remains of the space in which the vein has been formed?"

6.—"A consideration of the materials of which many veins are composed proves in so incontestable a manner that veins were originally empty fissures, that no doubt can now remain on the subject. Certain veins are

filled with rolled matter, or water-borne stones; fragments of adjacent rocks are often found in the middle of the vein; débris of the substance of a vein is sometimes found in considerable quantities in the same vein; the occurrence of petrifaction in veins—rock-salt and coal substances of very recent formation are found in veins—the occurrence of materials of mountain rocks in veins—all these go to show that they were originally open fissures."

7.—"The mode assigned for the formation of the spaces now occupied by veins is still further demonstrated by the relation which veins have to one another: as their intersecting one another, their shifting one another, their splitting one another into branches, their joining and accompanying one another, their cutting off one another. All these peculiarities are produced by the effects of a new fissure upon one that is older."

8.—"The relation which veins bear to the rocks and beds in which they occur, or the manner in which they are found in them, proves still further that they have been fissures."

9.—"If we examine with attention the interior structure of veins that are composed of different kinds of minerals we perceive them to have been originally open fissures which have been afterwards filled by degrees. Such veins are composed of beds arranged in a direction parallel to their sides; their crystallizations show these beds to have been deposited successively on each other, and that those next the wall have been first formed."

C. Bernhard Cotta is one of the most celebrated of the German geologists who have seriously dealt with the subject of the formation of ore-veins.* Professor Cotta's memoir is usually thought to be one of the completest expositions of the hypothesis with which it deals. It appears desirable that a somewhat careful abstract of this contribution to science should be placed before the readers.

The observed relations between crystalline and eruptive rocks and metalliferous deposits have been already dealt with. It is nearly a constant fact that all metalliferous deposits are always found connected with those geological formations and those intrusive rocks which are generally referred to igneous action. The first difficulty with which Cotta grappled is in the endeavour to answer the question, Whence are the metalliferous contents of mineral veins derived?

Three views have been adopted by different schools. One argues the ore deposits have been derived from above; another insists upon it that all metalliferous matter has been derived from some subterranean source—some suppose by the agency of hot springs, others think by vapour jets charged with metallic matter—while others would refer them directly to igneous action, such as produces Granite veins and Elvan courses, &c.

Professor Cotta leans to the hypothesis that these deposits are produced by segregation from the enclosing rock. This hypothesis—theory it is not—deserves the closest consideration, and strong evidence can be brought forward in support of it. It does not, however, account for the original

* "Gangstudien," vol. i. p. 85. By C. Bernhard Cotta, Professor of Geognosy at the Mining Academy of Freyberg. The works of C. Bernhard Cotta range from 1832 to 1877. His book on Mineral Deposits was published in Freyberg in 1855. This work, "Die Lehre von den Erzlagerstätten," has been translated into English by Frederick Prime, and published in New York in 1870.

source of the metals—by what agency or physical power were the metals introduced into the rocks from which they are supposed to be derived. It fails to explain the abundant distribution of the metallic ores in one district—for example, Cornwall—while in other districts, in the same character of rock—in Leicestershire, for instance—they are absent.

Metallic ores generally occur in veins which take a given direction and are of a definite size, the direction being in many districts associated with characteristic ores. But the direction of mineral lodes does not in separate districts give rise to the same kinds of deposit. Metallic deposits again are not always found in veins; they often occur in beds, in nodules, and in "*stocks*," irregular and indefinite masses. With the veins of Granite, or Elvan, or Greenstone we have no concern; the veins producing the useful metals—and these are generally fissured veins—are the only ones with which we have to deal.

The formation of mineral veins is intimately connected with the formation, or metamorphism of certain rocks, and is a certain effect of special geological causes. Particular species of ores are found in veins with very varied combinations and under very diverse circumstances. With the exception of iron-stone, mineral veins are universally found in the older rocks, more especially in crystalline schists, in the eruptive and grauwacke formations, but rarely in the newer sedimentary rocks; their occurrence is equally rare in trachytic, basaltic, or phonolitic rocks. It is not supposed that the massive rocks are the original bearers of the contents of ore-veins. Many metalliferous deposits are undoubtedly due to segregation, but it completely fails to account for the abundant distribution of the metallic ores in some districts, while in others, in the same class of rocks, there are no ore-veins or deposits to be found. The theory of metallic ores from beneath has been suggested by many, but this too is met with contradictions on every side. The near relation between the crystalline and eruptive rocks and metalliferous deposits is universally believed in, because universally observed, although even here are exceptions; but it has never been accounted for in anything like a satisfactory manner. Metallic ores occur in abundance in veins of a definite size and direction; the direction being constantly associated in certain districts with characteristic ores. Cotta holds that *metals originate below* out of the eruptive rocks, which, accepting the theory of gradual refrigeration, are assumed to form portions of the original fluid nucleus. There is objection to this, for although metallic ores are generally found in connection with eruptive rocks, particularly near their junction, they seldom occur in any quantity in them; and in cases where they have been so found they are only rich near the surface, and the ore totally fails on sinking deeper into the crystalline rocks. One would naturally think that if the ore came from below it would be richer the deeper we penetrated the Earth's crust, but the result of Cornish mining proves this to be incorrect, for in Granite the ore generally becomes poorer the deeper the miner works. Cotta meets this objection by saying that ore should only be sought where a rapid cooling of the eruptive mass has occurred, and as this rapid cooling is found to have occurred in vein-masses, such as porphyry or Elvan, and in small "stock masses," or on the contact and edge surface of the larger masses, his theory so far,

holds good, for it is in just such positions that the ore-deposits are most abundant.

The contents of the vein varies with its direction; this, he says, is "nothing else than the products of unequal stadii of cooling of one and the same vein-forming process." The upheaval of the Earth's crust must have produced fissures in nearly parallel groups in the same locality at the same time; these, one can imagine, would be filled with such minerals as were passing in solution from the eruptive rock through the veins, and were capable of being precipitated, at the then state of the temperature and pressure. If we suppose a subsequent change in the direction of the elevating force, we should then have a new set of parallel fissures, but with a different direction. These would in their turn become filled with such minerals as were then in circulation through the vein region, and were capable of being deposited at the temperature existing at that period. We may imagine a long lapse of time between the two fissure groups, then one might suppose there would be a great alteration in temperature, and another mineral would be deposited; although it might perhaps have been flowing in solution at the time of the first upheaval it could not be deposited, the higher temperature having kept it in a state of solution. The older ores are not found in the newer fissures for the like reason, the temperature had gradually become too low to enable the circulating fluid to hold them in solution. There is a strong analogy found to exist between the relative age and general characteristics of veins in countries widely apart, due to the analogous consequences of local eruptions. Cotta found in the Freyberg veins proofs of his general theory; the older veins are generally massive, while the newer ones are always banded or layer-like in form. It is possible that the newer veins were formed by *infiltration*, but that theory would not hold good for all ore-veins; tin ore is found in some places where it may be due to infiltration, but in others this would appear to be an impossible origin.

Fournet generally follows Werner in his hypotheses, but he differs from him as to the extreme regularity which is sometimes noticed in veins; and remarks: "When, for example, the veins contain fragments of the adjacent rock imbedded in their mass, the ore in preference attaches itself around them, enveloping them in a bed of greater or less thickness."* He notices that this fact is frequent in the mines of the Hartz, whence the *sulphide of lead* obtains the name of *ringertz*, or ring ore; but states, however, that the veins of Pontgibaud give evidence of successive openings.

M. Albert Louis Necker read, in 1833, before the Geological Society of London, a paper on Metalliferous Deposits, of which the following is a carefully made abstract.†

The doctrine of the sublimation of the metalliferous contents of veins from igneous matter occurred to the author twelve years before from observing the deposition of specular iron on the cooled lateral edges of a stream of lava flowing down the side of Vesuvius, and he was induced from that cir-

* "Études sur les Dépôts Métallifères."

† M. Albert Louis Necker, "An Attempt to bring under Geological Laws the relative Position of Metalliferous Deposits with regard to the Rock Formations of which the Crust of the Earth is formed." ("Transactions of the Geological Society of London." Second Series, vol. iii. p. 494. 1835.)

cumstance to institute a series of inquiries. In further prosecution of which he proposes in the memoir the following questions:—

1.—Is there near each of the known metalliferous deposits any unstratified rock?

2.—If none is to be found in the immediate vicinity of such deposits, is there no evidence, derived from the geological constitution of the district, which would lead to the belief that an unstratified rock may extend under the metalliferous district, and at no great distance from the surface of the country?

3.—Do metalliferous deposits exist entirely disconnected from unstratified rock?

With respect to the first of these questions the author endeavours to show—by copious references to works on England, Scotland, Ireland, Norway, France, Germany, Hungary, the Southern Alps, Russia, and the northern shore of the Black Sea—that the great mining districts of all these countries are immediately connected with unstratified rocks, and in further support of this solution of the first question, he mentions the metalliferous porphyries of Mexico and the auriferous Granites of the Orinoco, but he observes that his knowledge of the mining countries of South America is not sufficient to enable him to state their general geological connections.*

With reference to the second question, the probable associations of metallic veins with unstratified rocks—though the latter are not visible in the immediate neighbourhood of the former—the author gives a section of the country between Valorsine and Servoz, and points out the probable extension of the Granite of Valorsine under the Arguelles Rouges and Breven—composed of protogine, chlorite, and talcose schists—to the immediate vicinity of the mines of Servoz, which are situated in the latter formation. He also refers to the metallic deposits of Wanlock Head, the Lead Hills, and of Northumberland, and to several districts in Europe, all of which occur in districts where unstratified rocks are known to exist. It will be seen, by referring to the chapter devoted to rocks, that the mines in Scotland and Northumberland do occur in stratified rocks, but they are frequently penetrated by rocks of igneous origin, and consequently unstratified.

In reply to the third question, the author enumerates the mines of the Netherlands, the copper slate of Mansfield and Thuringia, &c. &c., the veins of galena in the Inferior Oolite near Frome, in the Magnesian Limestone of Durham, and the Mountain Limestone generally.

The author next gives, as an illustration, a sketch of several countries and of the western part of England. He shows that metallic deposits are totally wanting in the district extending from the foot of the Alps across the valley of Lake Leman, the Jura chain, and the plains of Franche Comte and Burgundy, and in the Oolitic and tertiary formations of the north-west of France. He also states—which has been previously pointed out—that in the tertiary and secondary formations of England, as far as Devonshire, there are no metalliferous deposits, but that as soon as the unstratified rocks recommence metallic veins reappear.

* Surely the Clay-Slate—*killas*—of Cornwall and the Devonian rocks must be regarded as stratified rocks. These may be considered as essentially metalliferous rocks.

Lastly, M. Necker states, that ores are more abundant in Granite, certain Porphyries, Syenites, Amygdaloids, and Trap—which he calls underlying unstratified rocks—than in the newer Dolorites, Porphyrites, and the true volcanic formations, which he distinguishes by the term of "underlying stratified rocks;" and he alludes to the assistance which the practical miner would derive from attending to this distinction, as well as to the connection of igneous with metalliferous formations.

Mr. R. W. Fox, of Falmouth, who had, for a considerable portion of his long and well-spent life, directed his attention to the subterranean phenomena —which he had the best possible opportunity of studying—in the Cornish mines—published an elaborate paper on mineral veins.* This memoir is of so high a character, it shows in every part so fully the operation of the mind of the philosopher, that it is to be regretted we are not enabled to reproduce it. Compelled, however, by the extent of the subject and the limits of space, we must confine attention to the "Recapitulation." It may be allowable to state that all the leading points of the inquiry are very clearly enunciated in it.

Mr. Fox thus summarises his views:—

"1.—That, admitting the origin of mineral veins to have been derived from fissures in the Earth, there is reason to believe that the latter may have been produced by different causes, and at various intervals; also that many of them have been enlarged from time to time.

"2.—That the accumulation of mineral deposits in such fissures has been likewise progressive, and that the evidences afforded by the resemblance of the vein-stones to the several enclosing rocks, and the arrangement and subdivisions of the contents of veins, are decidedly in favour of both these conclusions, independently of other arguments based on mechanical principles.

"3.—That the phenomena of veins seem to indicate that many of the fissures penetrate to a great depth, and into regions of very high temperature; and that, consequently, the water which they contained must have circulated upwards, and downwards, with greater or less rapidity.

"4.—That since the solvent power of water seems to increase in some ratio to the augmentation of its temperature, it is obvious that it would tend to dissolve some substances at a great depth, which it would deposit more or less in the course of its ascent through cooler portions of water; and also in consequence of its partial evaporation on reaching the surface.

"5.—That a part of the earthy contents of veins, and more especially silica or quartz, was apparently accumulated in this manner, and usually combined more or less with matter otherwise deposited.

"6.—That rocks, clay, &c., containing different saline solutions and metalliferous substances, in contact with water, charged in many instances with other salts, were calculated to produce electrical action; and that this action was probably much increased by the circulation of the water and differences of temperature; but more particularly by the existence of compressed and heated water, metallic bodies, &c., at or near the bottom of the fissures.

* "Transactions of the Royal Cornwall Polytechnic Society," vol. i.

"7.—That, since the water in the fissures containing metallic or earthy salts was a conductor of electricity, especially when heated, and in a very superior degree to the rocks themselves, it is evident that, in conformity with the laws of electro-magnetism, the currents of electricity would, if not otherwise controlled, pass towards the west, through such fissures as were most nearly at right angles to the magnetic meridian at the time.

"8.—That the more soluble metallic and earthy salts may have been decomposed by the agency of such electric currents, and the bases been thereby determined in most instances towards the electro-negative pole, or rock; that tin, however, under these circumstances is only partly deposited at the electro-negative pole, and partly at the electro-positive pole, in the state of a peroxide; and that the properties of this metal seem to bear on its positions in the lodes; and especially to explain why copper is sometimes found with it, and sometimes distinctly separated from it.

"9.—That the position of one rock with respect to another, or to a series of other rocks, may, as well as their relative saline or metallic contents, temperature, &c., have had a decided influence on the deposition of minerals on them by electrical agency, so that a given rock may have been *electro-positive* in one situation, and *electro-negative* in another, in regard to other neighbouring rocks, as this is quite consistent with voltaic phenomena.

"10.—That the evolution of sulphuretted hydrogen and the tendency of some metals when in solution to absorb oxygen, and become insoluble, may in many instances have interfered with the regular arrangement of the metals, such as electricity would have effected, and that hence many anomalies may have arisen, especially in relation to tin.

"11.—That the electrical reaction of the different metalliferous bodies and of masses of ore on each other, after their deposition in the fissures, may have corrected such anomalies, in some instances, and that they may have given rise to them in others, by changing the direction of the electric currents, and thus modifying the relative positions of the deposits; and that the pseudomorphous crystals of various descriptions, as well as other phenomena observable in mines, fully prove that some such secondary action must have taken place.

"12.—That cross veins may have been filled mechanically or by the decomposition of silica from a state of solution, or by both these means, and that the striated and radiated structure of quartz may be owing to the tendency of electricity under ordinary circumstances, to pass transversely rather than longitudinally, through north and south veins.

"13.—That, assuming the proofs of the progressive opening and filling of lodes and cross veins to be admitted, it seems to follow that many intersections may have been caused by the more ready accumulation of clay and other mechanical matter, and even of silica from its solution, than of the more slowly formed metalliferous or crystalline deposits.

"14.—That the frequent occurrence of a mass of ore in that part of a lode which is intersected by a cross vein, and also of small branches of ore from a dislocated part of a lode on one side of a cross vein, without there being corresponding veins near the other part of the lode on the opposite side of the cross vein, afford strong evidence of the deposition of the ore in

such cases after the intersection took place; and that it was accumulated in the east and west vein rather than in the north and south one by the influence of electro-magnetism.

"15.—That the small veins of copper and tin ore which are often found in cross veins, between the dislocated parts of lodes, and the frequent occurrence of more considerable, and yet for the most part very limited, quantities of these ores in the former, in the immediate vicinity of intersections, are additional arguments in favour of the operation of the same definite agency.

"16.—That the secondary fissures, resulting from the cracking off of larger or smaller masses of the hanging sides of veins, may have been partly filled, in many instances, by the electric action of different portions of ore on each other, and that secondary lodes may have been formed at right angles to parallel east and west lodes, in consequence of the reciprocal action of the latter.

"17.—That many other phenomena of mineral veins, including those of a mechanical character, such as the occurrence of *horses*, *heaves*, &c., appear to be capable of satisfactory explanation on the principles which have been laid down."

Imperfect, and limited, as is our acquaintance with mineral veins, enough is known to excite our admiration in the order and fitness which prevail amongst them. We observe that many of the most useful metals are the most abundant; and the fact that they are generally confined to certain veins, and to portions of them only, is perhaps of greater import than we might at first suppose; for had they been disseminated in the strata, or even dispersed throughout all mineral veins, the labour required to obtain them would have rendered them practically useless; or had they, on the other hand, been much more concentrated, their rapid exhaustion might entail incalculable injury on future generations.

Again, we remark that few metals are found in a native state, and those very sparingly; were it otherwise, there is good reason to believe that their electric action and reaction would have been so energetic, that some of the electro-positive metals could not have been permanently deposited. Had the metals generally existed in combination with oxygen or acids, their electric action would have been reduced to a minimum quantity; in which case many metallic and other solutions might, from being but partially decomposed, have found their way to the surface and impregnated the springs with their deleterious qualities. Sulphur appears to be the only component which enables metals to effect all the required conditions, and this proves to be the combination in which they most frequently occur. It has already been mentioned that such of the metallic sulphides as conduct electricity are highly electro-negative, and that their reciprocal action in most instances is so nearly in equilibrio as to prevent considerable changes; nevertheless they seem to possess sufficient electric activity to act upon other bodies, and to decompose saline solutions which may be exposed to their influence; and who knows how important such electrical filtration of the ascending water may be to organic existence at the surface of the earth?

Some of the cross courses appear to be channels for conducting the water between different lodes; and the flucan veins, by occasionally intercepting

it, tend to prevent the too great drainage of the land which would otherwise attend mining operations, whilst at the same time they enable the miner to prosecute his labour underground to a much greater depth than would otherwise have been practicable.

Considering the nature and arrangements of mineral veins under the surface, it can scarcely be doubted that the *endosmose* and *exosmose* processes must prevail, more or less, within the Earth, and tend to cause differences in the water level on the opposite sides of flucan courses. This influence—as has been before remarked—may be sometimes exerted in the same direction through a series of parallel clay veins, so as to produce successive elevations of the water, and thus affect the relative heights of springs. There are good grounds for believing that some of the most occult phenomena connected with respiration, and with the causes active in producing the animal and vegetable secretions, depend on the same process, which is itself apparently a modified form of electrical agency.

This at least is certain, that the action of electricity is not confined to the surface of the Earth; and it is more than probable that it is inherent in all matter in some modified form; so that, should the Hand that produced it suspend its operation but for one moment, animal and vegetable life would be universally extinguished and the mineral world become again chaotic.

The property which water possesses, in common with all other fluids, to ascend when heated, and to the influence of this property, in conjunction with the high temperature of the interior of the Earth, in the filling of fissures with mineral deposits, has been already alluded to.

Thermal springs seem to be a result of similar causes, and it is unnecessary to enlarge on their uses to mankind. Were it not for this law of fluids, the great ocean-currents which circulate between the polar and equatorial regions,—tending to equalise the temperature of the Earth's surface,—would cease to flow, and the atmosphere would be comparatively stagnant and unfit for respiration.

Evidences might be multiplied, almost without limit, to show the perfect adaptation of simple general laws to every possible case in the whole circle of creation. We can, however, detect their existence only by their effects, for our perceptions are far too limited, and our comprehensions too feeble, to understand the elementary constitution even of the simplest form of matter. There is, nevertheless, in all nature a harmony of parts, and a consistency of operation, calculated to excite our reverence and gratitude towards her Almighty Author, whose infinite foreknowledge and goodness thus forcibly manifest themselves in the perfect adaptation of physical laws to every existing circumstance.

Amongst writers the most deserving of attention on this interesting question must be named—

William Jory Henwood, whose "Metalliferous Deposits of Cornwall and Devon" contains a larger number of facts—the result of personal observation—than are to be found in any work in any language.

Westgarth Forster, in his "Treatise on a Section of the Strata," published in 1809, gives valuable information on the mineral veins of the northern counties. A new edition has just been published (1883).

Farey, in his "Derbyshire," gives useful information relative to the phenomena of the lead mines of Derbyshire (1811).

John Williams, in his "Natural History of the Mineral Kingdom" (1789) and other works, describes the peculiarities of several separate localities.

Joseph Fournet, in 1834, published his "Études sur les Dépôts Métallifères," which contains important observations.

Sir Henry T. de la Beche, in his "Report of the Geology of Cornwall, Devon, and West Somerset," published in 1839, describes very fully the mineral veins and faults of the district which he surveyed.

In addition to these, it appears necessary to refer to the work of J. D. Whitney, of the United States,* who has been long connected with the American Mineral Survey. He defines a vein—as a geological and mining term—to be "an aggregation of mineral matter of indefinite length and breadth, and of comparatively small thickness, differing in character from and posterior in formation to the rocks which enclose it." Following Cotta, Whitney divides mineral veins into *veins of sedimentary origin*, *veins of attrition*,—*veins of infiltration or stalactitic veins*,—*plutonic veins*,—*segregated veins*, and *metalliferous veins proper*. He refers to the several hypotheses which have been promulgated, and remarks upon them as follows:—

"1.—The veins originated contemporaneously with the rock in which they are contained, and are, so to speak, a mere accidental phenomenon, not governed by any fixed laws of formation. This theory may be dismissed at once, as entirely at variance with all the facts, as unworthy of consideration." —(That some vein formations are contemporaneous with the formation of the rock—produced probably during the consolidation thereof—many examples will prove.)

"2.—Veins have originated in the filling of fissures by injection of metallic and mineral matter in a state of igneous fluidity from below. . . . . Such phenomena, however, have only been observed in isolated cases, while usually the appearance of the walls, and the distribution of the mineral matter and ore between them, in true metallic veins, is such as to make this hypothesis of their formation entirely untenable."—(This is not a thoughtful assertion. In Granitic veins and Elvan courses metallic ores are occasionally found; these must, therefore, have been produced in a state of igneous fusion.)

"3.—The theory of formation by sublimation, according to which vein fissures were filled by the volatilization of metallic matter from the great centre of chemical action beneath, namely, the ignited interior of the Earth." —(That such may have been the origin of some metalliferous deposits, and that this agency may have contributed in some degree to the filling of veins, cannot be denied.)

"4.—The theory proposed by Werner presupposes a chemical solution covering the region in which the veins are found. . . . . In the sense in which this mode of formation was understood by Werner, but little importance can be attached to it.

"5.—*The Theory of Lateral Secretion.*—The main idea is that of a segre-

* "The Metallic Wealth of the United States described and compared with that of other Countries." By J. D. Whitney. Philadelphia: 1854.

gation of the mineral and metalliferous particles from the adjoining rocks in a state of chemical solution, and their deposition upon the sides of a previously formed fissure under the influence of electro-chemical forces."—(This view is directly connected with the electricity of mineral lodes, which should be studied.)

Although Mr. Whitney's "Metallic Wealth" indicates an imperfect generalization, it exhibits very superior powers of observation, and the volume is a real contribution of value to every thoughtful miner.

Having stated the more important authorities upon whom reliance has been placed for contributions as to the phenomena connected with the formation of mineral deposits, and given a clear expression of their views, a concise statement will presently be made from which it is hoped satisfactory conclusions may be drawn.

A few words are demanded on the views entertained by Mr. W. Wallace, who, in 1861, produced an important work on the Alston Moor district, based on an intimate knowledge of the mines of that locality, in which he put forth some original thoughts on the laws regulating the mineral deposits. From that work—and from correspondence with its author—the following notes on the conditions connected with the deposit of lead, &c., in the carboniferous rocks in the north of England have been compiled.*

1. The carboniferous rocks in which lead is found may be separated into two groups, those above the Great Limestone inclusive, and those below it. In Alston Moor the highly metalliferous portion is about 420 feet in thickness; this portion comprehends all the strata between the top of the Slate sills and the bottom of the Great Limestone. The shale beds lying between each stratum, however, rarely contain lead ore. The less metalliferous portion comprehends all the rocks below the Great Limestone, the Tynebottom Limestone, under conditions, excepted.

2. In both class of rocks large portions of the veins contain little or no lead ore; but this is more especially the case in the less metalliferous portion.

3. The deposits of lead, in both class of rocks, are invariably connected with conditions which are favourable to the descent of water from the surface and its circulation in each stratum in a longitudinal direction in the vein. The deposits of lead in the less metalliferous rocks are, with a few exceptions, poor, and extend a shorter distance from the surface than in the more metalliferous rocks.

4. Water is prevented from descending into any particular stratum by the great thickness of superincumbent strata. Under the summit of mountains the veins contain little or no lead, even in the metalliferous Great Limestone when it is lying at a great depth below the surface. Should rich deposits be found in such a position they are due to a combination of causes which rarely occur—to the formation of valleys running in opposite directions on each side of the mountain, to a rise of the strata at right angles to the vein, to the opposite side of the mountain, the strata being broken up with intersecting fissures. These conditions cause the water, which sinks on one side of the mountain, to flow to the other; and perhaps there are other

* "The Laws which regulate the Deposition of Lead Ore in Veins, illustrated by the Mining District of Alston Moor." By William Wallace.

especial conditions which have not come under observation. The descent of water is also affected by the steepness of the sides of the mountains. Where the sides are steep, water flows rapidly over the surface, and less of it sinks into the rocks.

5. The descent and circulation of water to a great depth are occasionally affected by the rise of strata, as shown in Fig. 47, the water descending in fissures in highly inclined strata and ascending to the surface in the vein. These conditions are connected with the rich lead deposits in Stonecroft vein near Haydon Bridge.

6. The descent of water is affected by the dishing in of the side of the mountain, and the quantity of water which circulates in the vein is proportional to the extent of gathering ground in a higher situation than that traversed by the vein. After its descent into the rocks it flows to the veins in channels, or rather in weak intersecting cracks or fissures, which frequently traverse the rich portion of veins in an oblique direction. In consequence of the conditions connected with the descent of water the richest deposits of lead are generally found at no great distance from the outcropping of the containing rock. Veins which run on the sides of a mountain in a direction nearly parallel with the valleys contain more extensive deposits of lead than those which cross the valleys at right angles.

7. The circulation of water in the veins is affected by the inclination of the strata in the direction of the vein. The richest deposits are found in that portion of strata which is the most elevated; for instance, on the side of a powerful cross vein (Fig. 50); thus:—

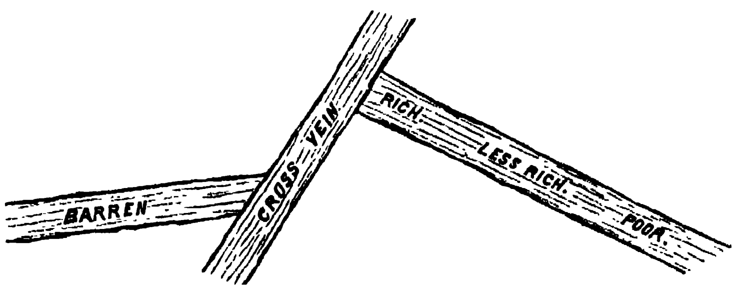


Fig. 50.

The circulation of water is dependent upon an outlet at a lower level.

8. Under the beds of the principal rivers—not those streams which flow rapidly down the sides of the mountains—the water may sink, but it cannot circulate; consequently, in the most metalliferous rocks, lead has only rarely been deposited even at a moderate depth below the surface; generally the veins contain no lead. At great depths not only lead but all other vein minerals are entirely absent.

9. Near the surface the contents of veins are invariably in a state of decomposition, the higher the elevation on the sides of the mountains the greater is the amount of decomposition, unless the vein has been filled with the insoluble sulphate of barytes. The carbonates of lead and zinc are formed from the decomposition of the sulphides and the combination of their oxides with carbonic acid.

10. The water that falls from the atmosphere contains from 6 to 8 per cent.

of oxygen in solution. As the water descends the oxygen disappears in the destructive oxidation of the rocks and contents of veins, &c. It would, therefore, appear that until the absorption of the free oxygen from the water is entirely effected, lead and the other accompanying vein minerals cannot be deposited. It is also probable that lead is never deposited very near the surface; though from subsequent denudation, greatly effected during the glacial epoch, it is not unfrequently found in the clays and broken rock near the surface. In some few instances the form of the surface has been greatly altered since the deposit of ore; but generally, though the mountains have been denuded, their outlines remain much the same.

11. That water does not lose its solvent power by the deprivation of its free oxygen is evident from the enormous quantity of rock, chiefly Limestone, which has in many places been dissolved, and the caverns formed, refilled with crystalline substances. It is probable that the dissolution of the rock and the refilling were carried on at the same time, for it is certain that, in many instances in the Westmoreland mines, the space could not possibly have remained open after the disappearance of the Limestone, but would have been filled with the soft overlying shale. Many of these crystalline substances are totally different from the rock which once filled the space they now occupy—carbonates of lime and iron, fluorides of lime, sulphides of iron, lead, and zinc; and in the Westmoreland mines, sulphate of barytes and sulphide of lead, with scarcely any other kind of mineral. The oxides, however, are not there; even the carbonate of iron, so easily converted into an oxide, retains its pearly brightness. Where this mineral is found partially changed into an oxide, a destructive agent has commenced its work. But by what enchantment have these wonderful changes been effected in the deep caverns of the Earth, so strangely different from any that are to be found at the surface?

12. The sublimation of the metals and other foreign substances from beneath is—to use the words of Professor Whitney in reference to the lead deposits of the Upper Mississippi—"an impossibility, absolute and entire." Taking into consideration the facts connected with the metallic deposits, it is evident that the only source from which they can be derived is the Limestones and Sandstones forming the enclosing rocks, the laws of chemical combinations being unknown. It is probable that sulphuretted hydrogen, often present in the mines, is one of the chief agents. This opinion is sanctioned by Professor Whitney; and it is probable that carbonic and fluoric acids play important parts in the formation of minerals, the latter particularly so, in the early stages of the process. Limestone which has not been removed is frequently changed into a very hard substance by the absorption of carbonic acid, and the loss of some of the calcium.

13. It is probable that deposits of lead and other minerals are being formed and destroyed in different parts of a vein at the same time. The metallic deposits must have shared the fate of the containing rocks which once filled up the valleys. These processes of composition and destruction have been in operation throughout periods of past time, the duration of which we can form very little conception.

Notwithstanding the eminence of the authors named, as authorities on

the question of mineral lode formation, it must be admitted that their hypotheses fail to carry to the mind of the careful observer that conviction which must be established before any satisfactory theory can be adopted.

Among the hypotheses, we find that the following are put strongly forward in explanation of the formation of *mineral lodes.* That is, accepting the geological view of the formation of the fissures in which the metallic ores are accumulated, they attempt to explain the process by which the contents of these fissures are deposited.

(*a.*) *Contemporaneous formation* involves the idea of a mass of rock-matter being produced containing metallic matter, or the mineralised ores in mechanical mixture or in chemical combination with it, which as the rock consolidates separates and forms veins, crystalline or otherwise, spreading through the clayey, pasty rock. Metamorphic action has been referred to as producing some effect. It is very doubtful what this may mean, as we find mineral veins in Granite and in Slate, which have not undergone any such change as metamorphism implies.

(*b.*) *Segregation* may take place from the mineral matter which exists contemporaneously with the alumina, silica, or lime of the rock; or it may be produced during the infiltration of liquid matter holding metallic salts in solution, after the rock has partially consolidated, either by the action of heat or the influence of time. Therefore *segregation* may be considered as a phenomenon connected with contemporaneousness, or, as the result of subsequent mutations.

An example of this may be obtained by placing in a slightly porous cell of fine earthenware a solution of sulphate of copper. This will pass through the porous wall very slowly, and the water will be evaporated from the exterior surface. During this action metallic copper will be left in the pores of the cell, which, by increasing and crystallising, gradually produces fine cracks filled with films of metallic copper. Another condition may be mentioned under this head, although it involves the operation of chemical action and surface force (may we not adopt, as a convenient expression for this form of cohesive attraction, the term *epipolism?* The word was employed to express some phenomena of light, but as this was shown by Professor Stokes not to be dependent *on surface* it was abandoned.)

If to a solution of silver in a glass trough some grape-sugar be added, the silver will be revived and spread itself uniformly on the surface of the glass, as a bright mirror surface. If to a solution of silver we add carefully a few drops of hyposulphite of soda—not sufficient to produce a precipitate—and place this aside in the dark at perfect rest, after a period, a film of black sulphide of silver will form upon the sides of the vessel in which it is placed. Many other experiments might be mentioned in illustration, but when the influence of electrical force comes under notice they will be considered.

If a mass of clay is moistened with a weak solution of some metallic salt, such as the sulphate of copper, and it be allowed to dry slowly, after it has been kept for some time in a damp place, there will usually be found some small threadlike veins or little nodules of copper in the form of carbonate or oxide. These have been formed by a process of segregation.

In the Clay-Slate of St. Agnes—especially over the ground on which the waste of Trevaunance and Polberro mines is heaped—we find examples of nature working as we have illustrated in our small experiment. Sir Henry de la Beche gives two examples of Slate containing strings of oxide of tin.

The annexed woodcut (Fig. 51) is a sketch, on a reduced scale, of a specimen of slate containing strings of oxide of tin from St. Agnes, and illustrates

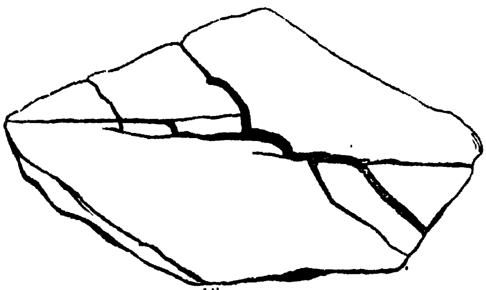


Fig. 51.

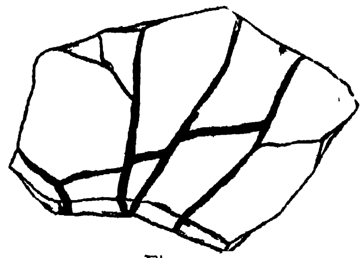


Fig. 52.

"complicated minor fractures subsequently filled with a metallic oxide." These specimens may be collected *in abundance* in St. Agnes, and they show an arrangement of parts which are *improperly termed heaves*, being nothing but numerous small fragments of slates, the result of minor fractures. Fig. 52 is another specimen, thought to be highly illustrative of such heaves, but they really are only fractures produced by the expansive force of crystallization.

The dissemination of tin extends over the whole of the promontory of St. Agnes—on which several mines are situated—to such an extent, that it has been said if an extensive battery of stamps were placed at Trevaunance pier and the entire hill crushed into powder and "dressed"—as the phrase is—the tin which would be obtained would pay for the machinery and the labour bestowed upon it. There are many other places where the oxide of tin is found as widely disseminated.

The Granite of *Cligger-head*, at Perranzabula, is traversed by thin veins of quartz, and both the Granite and the veins contain tin ore. During the summer months a solitary miner will be found breaking out masses of the decomposed Granite and allowing them to roll down to the beach at the base of the cliff. These masses are beaten, and broken, by the heavy waves which roll in during the winter season. The lighter constituents of the rock are washed away, but the fine grains of tin are, from their specific gravity, deposited below the sand. At low tides, when the weather permits, the miner is found gathering the oxide of tin, which has been separated for him by the ocean waves since he broke them from the beetling cliff.

(*c*.) *Lateral Infiltration.*—It will be readily understood that a fissure formed by any means in a Granite, or Slate, or Limestone rock, will form a passage through which the water filtering from the surface will find a channel for escape. During this process many of the salts held in solution will be deposited upon the faces of the rock exposed in the fissure. Gustavus Bischof* has accumulated information as to solvent powers of pure water,

* "Elements of Chemical and Physical Geology." By Gustav Bischof, Ph.D.

and of waters containing carbonic or other acids, but additional experiments are required. Is it not probable that waters derived from rocks of various descriptions may hold oxygen or *ozone*, or fluoric or silicic acids, and that these aid in dissolving the metals and earths it may meet with, in its slow infiltration through a great thickness of the rock?

(*d.*) *Descending Waters.*—These are only to be distinguished from the waters of infiltration, as being poured into the fissured channel from the surface of the Earth, accumulated by all those conditions which belong to surface drainage. Such waters will carry with them the materials which are found in running rivers and in springs.

(*e.*) *Ascending Influences.*—These will be waters varying in temperature, according to the temperature of the depth from which they ascend, or from the heat produced by the decomposition of pyritic ores in the strata through which it has passed. Or it may be water vapour—steam—formed by some igneous influence in operation at some considerable depth beneath the Earth's surface. Water vapour at elevated temperatures may possibly dissolve many substances not usually soluble in that fluid at a low temperature. This, consequently, cooling in its passage through the fissured rock, would part with some of the solid matter in solution, and deposit it on the sides of the crack.

(*f.*) *Sublimation.*—Many of the constituents of our mineral lodes are susceptible of being vaporised under the influence of intense heat: all our sulphides, arsenides, fluorides, and the like, might possibly have been formed in this way.

(*g.*) *Injection.*—Supposes the matter of lodes to have been injected into the rocks or fissures in a state of igneous fusion. The evidences of the conditions *e*, *f*, *g*, are to be found between St. Just and St. Ives, where both the Granite and the Slate are traversed by lodes, which may probably be due to the influence of an elevated temperature.

The central region is productive of tinstone, and in the district of St. Just and St. Austell the tin ore not only forms numerous thin veins, but is so generally disseminated as to be regarded as an ingredient of the rock. At Bejowans, in Sancreed, in the bed of a confluent which extends from Tregonebris to the coast at Lemorna—where the large Granite quarries are—we have the following section:—

1. Granitic sand and gravel mixed with small angular and subangular masses of Granite	6 to 12 ft.
2. Peat, in which nuts and branches and roots of hazel (?) are imbedded here and there	2 to 8 ft.
3. Granitic sand, gravel, and pebbles, interspersed with large boulders of Granite	6 inches.
4. The tin ground, being in a great measure wood tin of a divergingly fibrous stratum, with which crystals of quartz are sometimes imbedded	2 to 9 ft.

Where the Granite bed (shelf) is soft, the tin ore is the most plentiful. The rocks of the following districts have produced, and some of them are still producing, tin ore; all of them presenting the appearance of having been subjected to considerable heat.

Cold-harbour Moor, between Towednach Church and Amellibrea.

Tregilliow, on the confines of Ludgvan and St. Hilary: in the vale at the end of Marazion Marsh, the tin is diffused through matrices natural to it

in the metamorphic Slate veins. In *Sancreed*, the tin occurs in thick concretions, capping crystals of quartz.* And in *Sennen* it is found diffused extensively in rocks of admitted igneous origin.

At *Tregadgwith*, in St. Burian, similar conditions prevail.

At *Porkellis Moor*, in Wendron, at *Carn-wartha*, the disintegrated Granite contains short veins of quartz and schorl, impregnated with tin ore. At *Mean-vroar*, the veins discovered in the Granite shelf display the outcrops of small strings which were worked to advantage. From *Porkellis* to Trenear and thence to Helston tin ore is found, copiously disseminated in the rocks, which have evidently, at one time, been plastic by heat.

In 1878, Captain T. P. Rowe and Dr. C. Le Neve Foster read before the Royal Geological Society of Cornwall some observations on Balleswidden mine. This is so important a record of a mine which was abandoned in 1873, and produced in the thirty-six years it was working more than 12,000 tons of black tin (oxide of tin), of a value of £694,094, that the following extracts are made from it, especially as exhibiting the phenomena of stanniferous diffusion:—

"THE AWBOYS LODE is situated in the southern part of the mine. The bearing of this lode is about north 42° west (true) for more than a quarter of a mile; on going northwards it turns 10° more to the west. The dip is south-west, varying from 75° at the south-east part to 60° at the north-west extremity of the workings (*underlie*, 18 inches to 3 feet in a fathom). The structure of this lode deserves particular attention; the so-called lode consists of four or five small parallel tin veins, bounded on each side by a hard rock, locally known as *hard-work*, which merges into Granite. The total width of the lode varied from 10 to 20 feet, and averaged about 12 feet. *Each little vein or leader, known at Balleswidden as a gry, was generally about a half-inch thick, and rarely widened out to more than 4 inches. The gries rarely united with one another along the dip or the strike, but often dwindled away to a mere string or joint.* The filling-up of these little veins consisted of coarsely crystallised tinstone, with schorl, quartz, Gilbertite, and Kaolin (*prian*); a little wolfram, fluor-spar, bismuthine, and native copper were also sometimes met with. The little veins or *gries* were continually varying in productiveness; as a rule only one of them was rich in any given section, and as soon as it began to dwindle away one of the neighbouring ones began to improve. There was always a sharp and well-defined *wall* between the *gry* and the adjoining *hard-work*; and this was of importance to the miner, as it enabled him to separate the rich *gry* from the poorer rock adjoining it, and make a little parcel of *best work*. The greater part of the tin was contained in the *gries*.

"The *hard-work* on each side, from 2 to 6 inches wide, is a granular mixture of quartz, schorl, and Gilbertite, with a little mica, fluor-spar, and tinstone. The tinstone is almost always very finely disseminated through it. Occasionally pseudomorphs of quartz and of Gilbertite, after orthoclase, were observed in the *hard-work*, and coarsely crystallised tinstone has also been found filling up cavities left by the removal of the same mineral. There was never any *wall* or sharp plane of division between the *hard-work* and the

* "Manual of Mineralogy." Greg and Lettsom.

Granite. The portions of this rock lying between the bands of *hard-work* were often soft and decomposed in the middle, forming what the Balleswidden miners called *gook*. The Granite usually presented large and well-developed crystals of orthoclase.

"Fig. 53 shows the general appearance of the lode. A B C D E are *gries* bounded on each side by *hard-work*, and G G G G, &c., are the intervening bands of Granite, either decomposed for their entire width or only in the central part. G′ is the Granite on the sides of the lode.

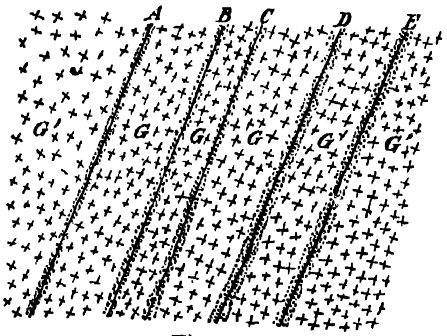


Fig. 53.

"At the south-east part of the mine the workings were shallow, and the lode was productive in some places up to the surface. The enclosing Granite was soft; but when it became hard in depth the lode fell off in productiveness. Proceeding to the north-west the lode continued to be rich to a greater and greater depth.

"PIE LODES.—The name *pie* was used at Balleswidden to denote a rock composed mainly of quartz, Gilbertite, schorl, and Cassiterite, often slightly cellular. There were two special *pie* lodes. One ran about east and west, and dipped north about 80°. It started off from Awboys lode and crossed the south lode. The other *pie* lode went off from the south lode, with a bearing of about south 20° east, and was nearly vertical. A cross section of one of these *pie* lodes would be much as shown in Fig. 54, whilst Fig. 55 gives the horizontal section where numerous joints are seen running into the *pie*. The stippled part in each of these woodcuts shows the extent of the ground worked away for tin.

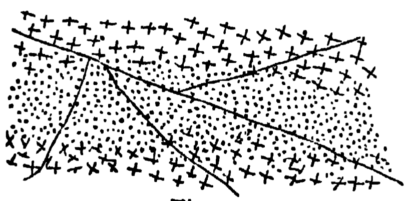


Fig. 54.

"Both the *pie* lodes were offshoots, as it were, of the main lodes; they usually gave out a good deal of water at their junction with the main lodes. The productiveness of the *pie* lodes decreased if schorl predominated over the Gilbertite. The usual thickness of the *pie* lodes was about 3 feet, but they increased to 6 feet occasionally, and then dwindled away all round the productive part to a mere string.

"The *pie* lodes are probably altered Granite, where, owing to some slightly different chemical action, there has been a larger amount of Gilbertite formed from the orthoclase.

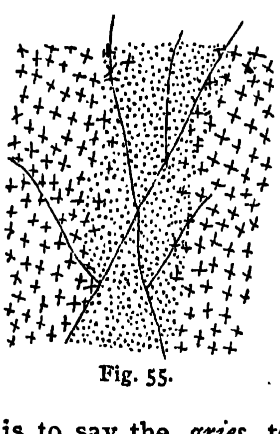


Fig. 55.

"The *tinstuff* obtained from the mine, that is to say the *gries*, together with the adjacent *hard-work*, produced about 60 lbs. of *black tin* to the ton of stuff, or rather more than 2½ per cent."

Ding Dong mine, in Gulval, is entirely in Granite, an Elvan course running through it. It has been worked for 150 fathoms from surface.

No lodes come to surface. The ore is all small. A lode 12 inches wide is regarded as a wide one. Strings run irregularly through the Granite in all directions. Sometimes a vertical lode is met with, but it lasts but a few fathoms and usually entirely dies out. Some of the strings lead to a good bunch of tin, but these bunches are not continuous, although they often yield a considerable quantity of ore. By the side of the Elvan course in this mine a small vein of tin was continuous, and rich.

The antiquity of Ding Dong is considerable. The chief agent said, "Many people say she was worked hundreds of years afore Christ."

The mass of Stanniferous Granite, in which this very old mine existed, lies partly in the parish of Madron, and partly in Gulval. The appearance of the rock is peculiar—it is Granite, with green and pale brown felspar and quartz and dark mica. The Granite is coarse-grained, porphyritic, and frequently decomposing. The main lodes which traverse it are known as the *Bossilliack*, which has a direction 30° south of west; *Malkin*, which has a similar direction; the *Bussa Trawn*, with a direction 33° west of north; and the *Bucca Trawn*, running north-west and south-east. The Bossilliack lode is split into several branches, which are filled with quartz, schorl, and felspar. The *Malkin lode* is exceedingly peculiar. It consists of quartz, schorl, felspar, and oxide of tin. At the 57-fathom level the lode has a northerly dip, generally varying from 77° to 84°. Three veins of disintegrated Granite traverse the lode. Two of them simply intersect, but the third heaves the lode 4 fathoms; it bears north-west, and dips east 82°. The lode varies in a peculiar manner—at 57 fathoms it consists of two veins of quartz, felspar, and schorl, with oxide of tin; at 68 and 80 fathoms a similar condition prevails; and immediately below 80 fathoms we find earthy-brown iron ore, chloride, and oxide of tin. The *Bussa Trawn lode* and the *Bucca Trawn* contain principally brown iron ore, with quartz and schorl. Within this comparatively limited sett there are laid down on the plans no less than twenty-two distinct lodes.* These lodes were constantly throwing out branches, and disseminating strings to such an extent as to appear to fill the Granite with mineralised veins. On the maps by the Geological Survey Ding Dong mine is indicated by two lodes only, both having a direction a little south of west; and these lodes are crossed by three *faults*, having a direction nearly magnetic north, which are partly mineralised. It is not easy to understand how this isolated portion of Granite became so stanniferous, situated as it is in the middle of the great Granite mass of West Cornwall, unless we refer to the action of heat maintaining a prolonged plastic state after the consolidation of the surrounding portion.

* The names given to these lodes were the following:—

1. Coit lode.
2. Red lode.
3. Stand lode.
4. Stratons lode.
5. Bussa lode.
6. Bucca lode.
7. Wig lode.
8. Scorran lode (4 branches).
9, 10. *Unnamed.*
11. Trawn lode.
12. Slide lode.
13. North Standard lode.
14. Jacobine lode.
15. Ventenega lode.
16. Bossilliack lode.
17. Afters lode.
18. Black lode.
19. Bolitho's lode.
20. Ding Dong lode.
21. Wheal Boys lode.
22. Cluckey lode.

This condition of the Stanniferous Granite gave rise to the deposits of detrital tin between Higher Carnon and Restronguet Creek. "At intervals within my recollection," says Mr. Henwood, "these works have been carried on by five several parties of speculators in succession. The first two as open works (the last of which afforded a profit of about £50,000); but by the other three in shafts sunk deeper than the bed of the inlet, and by drifts in which the miners worked whilst laden ships sailed overhead." The first of the mining works afforded a profit of about £28,000. The second eventuated in a loss of about £16,000.*

Mr. R. Thomas † thus describes these works: "The open stream works were found sufficiently profitable to induce the adventurers to extend their operations down the navigation nearly a mile and a half. But latterly the work has been carried on in another way. A shaft was sunk in the firm rock on the shore, and a drift was extended from the bottom, by which means the tin was obtained by removing only a small part of the mud which covered it. . . . . These operations have been sufficiently successful to induce the adventurers to extend their works half a mile further down: two shafts having been recently sunk through the mud in the middle of the creek, and secured by lining them with iron cylinders. The lower shaft is surrounded by an artificial island formed of stones and rubbish on which is erected a steam-engine."

About the middle of the navigable channel near Point, where the bed of Restronguet Creek is some 12 feet below high water at spring-tides, a shaft has been sunk by Messrs. John Taylor & Sons through the deposits named. The following section was in one case measured by *Taylor*, in the other by *Whitley*:—

	Taylor.	Whitley, C. E.
1. Mud of river very soft	6 ft.	7 to 9 ft.
2. Mud and coarse sand	8 ft.	9 ft.
3. Mud hardened	6 ft.	—
4. Mud mixed with oyster-shells	12 ft.	9 ft.
5. Mud hardened	31 ft.	36 ft.
6. The tin ground (*mean*)	4 ft.	6 in. to 6 ft

Gold has been found in the tin streams, and as usually derived from igneous rocks, this fact is interesting.

"Some five-and-thirty years ago" (written in 1873), "whilst examining a small parcel of stream tin from this district, I found amongst it a lump of gold nearly if not quite as large as a pea" (*Henwood*).

A piece of gold, in a matrix of quartz from Carnon Vale, in the Royal Institution of Cornwall, weighs 11 dwts. 6 grs.‡

Gold was found in the bed of the brook, from Tarnon-dean upwards as far as Trewedna water." §

Lower Creang.—Masses of flint and crystals of gold occur at wide intervals.

Trelog.—"The tin stream at Trelog was frequently mixed with grains of

* "On the Detrital Tin Ore of Cornwall." By William Jory Henwood.
† "History of Falmouth." By R. Thomas, Surveyor.
‡ "Manual of Mineralogy." By J. Mitchell.
§ "Gwennap: a Descriptive Poem." By W. Francis.

gold, mostly about the size of wheat, and sometimes as large as peas."—*Mr. J. Nicholls, proprietor, M.S.*

Newquay.—The raised beach at Fistral, near Newquay, frequently afforded granules of gold.

"Gold has been found mixed with stream tin ore in Kenwyn, Ladock, Probus, Creed, Saint Ewe, Saint Mewan, Gorvas, St. Stephens, St. Austell, Lanlivery, Lostwithiel, but the entire produce of the country can scarcely have exceeded a few pounds" (*Henwood*).

Carclaze mine, near St. Austell, is another remarkable example of a mass of decomposing Granite intersected by numberless veins and strings of tin ore, in the neighbourhood of which the Granite also contains disseminated tin. Professor Sedgwick* says of this district: "In all the crystalline Granitoid rocks of Cornwall there are also many masses and 'veins of segregation.' Such are the masses and veins of schorl rock, and some of them are metalliferous. The decomposing Granite of St. Austell Moor is traversed, and sometimes entirely superseded, by innumerable veins of this description."

Again the same geologist says, speaking of the open works at *Bunney*: "Tin is also disseminated in regular crystals both in the Granite and schorl rock, where we have no appearance of any regular vein distinguished from the rest of the formation." Are these stanniferous rocks igneous?

Mr. Henwood, speaking of the diffusion of metallic minerals through the rocks, says: "Small crystalline granules of tin are dispersed through and form an integral part of the Granite of Balleswidden,† Raggy-Rowal, *Wheal Vyvyan*, *Carclaze*, Kit-Hill, &c., of some portions of the Elvan courses at *The Wherry*, *Parbola*, *Relistian*, *Wheal Vor*, *Unity Wood*,‡ *Polberro*, and of the Slate of *Fat-work*. But for the opportune occurrence of copious streams at Carclase and Wheal Vyvyan, probably these mines would have remained unwrought and their physical structure unknown."

The Granite mass extending from Penzance and St. Ives to the Land's End is, with the exception of the district around St. Just, and a few localities on the coast, but slightly metalliferous. At Balleswidden, and at Ding Dong, we find exceptional conditions. It is necessary that attention should be directed again to the *course*, or bed of rock, in Balleswidden, called *the lode*. It bears about 30° north of west, and dips south 60°, 80°. It is composed of ill-defined and confused mixed crystals of felspar, quartz, a little white mica, and some schorl, among which considerable quantities of oxide of tin are irregularly distributed. This is worked from 12 to 30 feet in width, and it is traversed by numberless small veins which have a general coincidence with the mass, both in direction and dip. These are frequently mere lines in the rock, and but few of them are more than 3 or

* Address to the Geological Society, February 18th, 1831. ("Philosophical Magazine and Annals," 1831, ix. p. 2844.)

† "It is customary in almost every part of the county to cut up the sod as well as the heath growing on the downs for the purpose of fuel. An examination of the turf taken up at *Balleswidden* has brought to light the fact that it contains tin ore—a most striking proof of its universal diffusion through the coarse soil as well as the rock of that neighbourhood."—*Henwood*, "*On the Metalliferous Deposits of Cornwall.*" (*Geological Society of Cornwall.*)

‡ At *Wheal Unity Wood* both the Elvan courses are so rich in tin ore that they are worked as, and sometimes called, lodes.

4 inches wide; they consist almost entirely of oxide of tin, quartz, and schorl, and are generally very rich. They frequently divide, reunite, and possess all the ordinary character of lodes, and the cavities with which they abound are lined with minute but perfect crystals.

At Balnoon, in the Lelant district, the tin is found in *masses unconnected with any* lode, and disseminated through a hard and very coarse Granite. A few examples in other districts will prove instructive.

The Germans apply *stockwerk* (stock-work) to large masses of rock impregnated with metallic ores.* Beyond those already named, we have some very interesting examples of a similar kind near St. Austell. *Wheal Prosper and Michell* are open workings about half a mile west of Lanivet Church, between Bodmin and St. Austell. These workings are upwards of 800 yards in length, with a width of 30 yards, in the Clay-Slate. The rock is interpenetrated by numerous little tin veins running east 7° north, true. These veins are mere strings rarely more than ⅛ inch wide, and there are occasionally *caunter-lodes*, which are likewise stanniferous.

Mulberry mine, about a mile and a quarter north-west of Wheal Prosper, is a large open quarry about 300 yards long from north to south, and 30 yards wide at the bottom. At the north end the pit is about 120 feet deep, and 80 feet at the southern end. The Killas (clay-slate) dips at an angle of 45° degrees in a direction north 22° west, true, and it is traversed by branches or veins running north 7° west, dipping from 80° to 90° west and varying from mere joints to veins of 4 or 5 inches in width; and sometimes a *floor* or vein of tin follows the stratification.

Minear Downs, about 1⅛ mile from St. Austell, is a large open working about 200 yards long and 60 or 70 yards wide, having a depth of 120 feet. The strings in this quarry are often *mere cracks*, being occasionally ⅛ inch wide.

Carrigan is 2 miles north-east of Roche Rock. The stratum here is *greison*, which is merely altered Granite. This is worked open at Crogan Rock to a length of 100 yards, a width of 50 yards, and a depth of 60 feet. The mass is full of clay veins, or flucans, containing tin.

The tin ore obtained from the "*Stream Works*" near St. Austell has been derived from the Granite and the Slate rocks which rise above the valleys in which the detrital beds have been found. The examples which have been given will sufficiently prove this; and we have seen that there exists a large amount of evidence showing that considerable tracts of country have been removed by denudation and produced those detrital deposits. We have numerous examples of tin ore existing as one of the constituents of rocks which exhibit very marked mineral characters.

Sir Henry de la Beche says: "Those who have studied the decomposed Granite near St. Austell, traversed as it is by a multitude of branches and strings of oxide of tin, would have little difficulty in perceiving that if a body of water were made to rush over it, the decomposed Granite would be readily removed, and that the broken-up strings and branches of tin ore would be

* See C. Le Neve Foster, "On some Tin Stockwork in Cornwall." ("Quarterly Journal of the Geological Society," August, 1878.) J. H. Collins, "On the Hensbarrow Granite." ("Transactions of the Royal Cornwall Geological Society.")

rolled into pebbles and distributed just as the stream tin now occurs down the valleys in the neighbourhood."

The evidences of the decomposition of the Granite and the formation of Kaolin do not appear to be entirely satisfactory, but this is not the place to examine a very intricate problem. Suffice it to say that probably the vast masses of china-clay and china-stone which exist around St. Austell, and on Dartmoor, may represent imperfectly formed rather than perfect Granite, which has suffered decomposition either by the reaction of the atmosphere or of the drainage waters from the peaty mosses which usually rest upon its surface. The bed of the sea would be expected to yield large quantities of diluvial tin ore, seeing that all the rivers from the Granite hills flow into it; but this is not generally the case. A few instances may be named. In St. Just, on the beach a little below Little Bounds mine, some men occasionally are repaid for the labour they bestow. At Loo-pool Bar a little black tin has been found, and in 1860 a tin-furnace was discovered buried in the sands. From Gunwallow, Mr. John Jope Rogers, of Penrose—who was the owner of the dues there—received money for small quantities of tin found in the hollows of the rock. At Perranzabula, on the sands—especially around Perranporth—considerable quantities of black tin have been from time to time recovered. In nearly all these cases this tin has been derived from the breaking up of the cliffs around the coast. Those instances are given as showing how extensively tin is distributed through rocks which are usually regarded as of igneous origin. It may still be advantageous, as showing the enormous quantity of matter which has been removed, to give a few additional examples of the peculiar characteristics of the deposit of tin in the valleys of Cornwall.

We have already mentioned the stream works in Restronguet Creek. Mr. C. H. Taylor, of Devoran, who had for some years the management of the operations carried on in that estuary, gives the following description of them:

"The object of these works was to recover a valuable deposit of Stream Tin which is found under the water in Restronguet Creek, and lies *on* the rock beneath the mud and silt that form the bottom.

"The Carnon Valley, which has its outfall in the Restronguet Creek, was in the last century the site of one of the most important stream works in Cornwall; and the old streamers followed the tin bed some way down into the creek, keeping out the tide by means of large embankments, of which a great part still remain, and removing the whole of the overlying silt to get at the tin. The tide having broken in over the embankment about the year 1800, the works were then abandoned; but about 1822 the working of the tin bed was resumed by mining under the silt of the creek, and this was successfully carried on for about five years. Some time later a lower part of the creek was similarly worked, and operations were continued until 1843, the remains of which are still to be seen in the old mine on the island in the middle of the mouth of the creek.

"In 1871 the most recent operations were commenced for working the portion of the tin bed known to remain unwrought between the two old mines. Both of the old workings had been much troubled with water, the levels not being always deep enough to drain the dips in the rock; it was therefore decided in the new workings to drive a deep main level in the rock

at 4½ fathoms' depth below the tin bed, which should act as a drain, and also serve as a tramway level for removing the stuff.

"It was found that the covering of mud and sand above the tin shelf was about 60 feet in thickness; the bed of tin was from 1½ to 4 feet thick, resting immediately upon the rock. A shaft was sunk through the rock to a depth of 18 fathoms on the beach below high-water mark, and a level driven out to the middle of the creek 9 feet high and 5 feet wide. The tide was kept out of the shaft by means of a wall, built up from the rock, of timbering and puddle. An iron shaft was also sunk at the same time in the middle of the creek for securing good ventilation of the workings. It was sunk in a bank of soft mud covered 10 or 12 feet with water at high tide, a staging being made by piles driven 12 feet into the mud, and supported from sinking by cross timbers bolted to piles just below the surface of the mud. The shaft was constructed of iron cylinders in lengths of 6 feet. The first cylinder was made sharp at the bottom for entering the mud, and was sunk into the mud by the weight of two other cylinders upon it. The core was then cleaned out and further cylinders forced down by pressure from the chain of a crab-winch, and afterwards by the weight of barges loaded with stone, and made fast at high tide, so that the weight came on the cylinder as the tide fell. A total weight of about 250 tons was required to sink the cylinder as it neared the tin bed, which was about 3 feet thick at this part. About 78 feet of cylinder were sunk to make this shaft; it is about 4 feet above the engine shaft, and thus forms the upcast in the ventilation of the mine. The difference of 4 feet in the height of the two shafts is found sufficient to maintain thorough ventilation throughout the whole of the working by natural means alone, without the need of resorting to artificial methods for the purpose. From this shaft two levels were driven, east and west towards either shore of the creek, and from these, two parallel levels were cut at right angles to the first, which extended northwards for 90 fathoms. These served as the basis of the workings, but soon other levels followed, all of which had to be secured with timber as the mud quickly began to crush very heavily. In the two main levels a frame, or 'set,' is fixed at every 2½ feet; in the other levels the sets are smaller and further apart. Much injury occurs at times to these sets by the swelling down of the mud, but as this is gradual, and never sudden, they can always be replaced or repaired. The workings in the tin bed are quite dry, with the exception of the two main levels that are driven up the creek, where there is a little water coming in from the rock in the bottom of the levels. Not a drop of water finds its way through the mud, although at high tide there is a depth of 12 or 14 feet of water over it. The tin bed varies very much in thickness and in productiveness; in some places it is as much as 7 feet thick, and in others only 3 inches, and the produce varies from 15 per cent. to only 1-10th per cent. of black tin (oxide of tin). The top of the bed is generally nearly level, so that as the surface of the rock below rises or falls the gravel is thinner or thicker. The bottom of the bed is generally much the richest in tin, but there is sometimes a second floor of tin above richer than that below, and having a different quality of waste associated with it, as if deposited at a different period. Some of the boulders found in the bed weigh as much as 3 cwt. In the old workings, and also

recently in the new, some fossil remains of stags' horns and bones, &c., have been met with; and in washing the tin several small particles of gold have been found, some of nearly 4 grains weight. Much larger nuggets of gold are stated to have been found in the old workings. The mud immediately over the tin bed is often full of shells, some in good preservation; and in driving one of the two main levels the trunk of an oak-tree was met with, and had to be cut through; it was sound and tough, though soft, and was quite black throughout."

The tin deposit of the Pentuan Valley has been already referred to. We avail ourselves, however, of the following section of the "Happy Union Tin Stream," which gives some very interesting and important facts bearing on the sources from whence this immense mass of detrital matter has been derived.

"(*a.*) Tin ground of unequal thickness, according to the inequalities of the surface of Grauwacke beneath (3 to 10 feet). With it are rounded pieces of Granite and other rocks of the St. Austell hills, traversed by the valley, as also fragments of Grauwacke and Greenstone, which having been transported a short distance are more angular. Most of the tin occurs at the bottom of this bed, though it is sometimes found in the higher parts. The tin is from the size of the finest sand to pebbles of 10 lbs. weight; and some rocks, richly impregnated with tin, weighing 200 lbs. and upwards, have sometimes been found there. The small tin, which is known by the name of grain-tin, is of the best quality; the larger stones contain more waste, and sometimes also copper and mundic. Roots of trees are seen in this ground, and on the top of it oyster-shells still remain fastened to some of the large stones and the stumps of trees. The roots of the oak are in their natural position, and may be traced to their smallest fibres, even so deep as two feet; from the manner in which they spread, there can be no doubt but that the trees have grown and fallen on the spot where their roots are found.

"(*b.*) A stratum of dark silt, about 12 inches thick, apparently mixed with decomposed vegetable matter, and on the top of this a layer of leaves of trees, hazel-nuts, sticks, and moss, from 6 to 12 inches more. The moss appears in a perfect state, retaining almost its natural colour, and seems to have grown where it is now found. This layer of vegetable matter is about 30 feet below the level of the sea at low water, and about 48 feet at high-water spring tides. It is not found in particular spots only, but extends, with some interruptions, across the valley.

"(*c.*) A bed of sludge or silt, 10 feet thick, changing from a brownish to lead colour in particular places. The whole is sprinkled with recent shells, together with wood, hazel-nuts, and sometimes the bones and horns of deer, oxen, &c. The shells, particularly the flat ones, are frequently found in rows or layers; they are often double and closed, with their opening part upwards, so as to render it likely that the animals lived and died where their remains are now found.*

"(*d.*) A bed of sand, about 4 inches thick, contains (marine) shells, and the water which drains from it is nearly as salt as the sea, whilst all the water above and below it is fresh.

"(*e.*) Silt or clay, 2 feet thick.

"(*f.*) Sand, 20 feet thick. In all parts of this sand there are timber trees, chiefly oaks, lying in all directions, and also the remains of animals, such as parts of red deer, &c.† Bones of whales are found in it; the bones of a large one were discovered in the upper part of this bed, as well as those of others in the lower portions of it.

"(*g.*) A bed of rough river sand and gravel, here and there mixed with sea sand and silt, about 20 feet thick and extending to the surface. Mr. Colenso states that a short time before he described this section (1829) the remains of a row of wooden piles had been found in this sand, sharpened for the purpose of driving, and that they appeared to have been used in the construction of a wooden bridge for foot passengers; they crossed the valley, and were about 6 feet long, their tops being about 24 feet from the present surface, just on a level with the present low water at spring-tides. He remarks that

* These shells are of the same species as those which now exist in the neighbouring sea; their appearance in the lead-coloured silty clay strongly reminds the geologist of that of the shells in the sub-Apennine lead-coloured clays, such as those of Nice and other places.

Mr. Colenso states that, at about the time he wrote (1829), a piece of oak had been found in this silt, about 2 feet from the top, which appeared to have been brought into form by the hand of man. It was about 6 feet long, 1½ inch broad, and less than half an inch thick. It appeared to have floated in the sea, as at one end, which was much decayed, a small barnacle had fixed itself.

† Mr. Colenso notices human skulls as having been found in this sand.

if the sea-level had been then as now such a bridge would have been useless. These works are now abandoned; but in 1837 others were carried on higher up the valley on the south of the London Apprentice inn; from which it would appear that from the general rise of its bottom the sea had not entered this valley sufficiently high to permit marine deposits to be there accumulated. The tin ground was covered by gravels, sand, and silt, among which trees, chiefly oak, were irregularly distributed, the whole probably being the accumulation of river-drift during a long period of time."—*Contributed, in 1829, to De la Beche's "Geological Report of Cornwall and Devon," pages 401, 402, by Mr. Colenso.*

From the sources described black tin has been obtained from the earliest recorded time. As we have already shown, ancient tin smelting works have been found in all parts of Cornwall. Mr. Henwood has named five spots only, on which these curious remains of old British or Jewish metallurgy exist. The St. Austell moors alone would give a larger number, and the parishes of Sancreed, St. Just, Morva, and Zennor, to the west and north of Penzance, would produce several. The number of old slabs called "Jews'-house Tin," which have been recovered, are said by the same authority to be eighteen only. A far larger number of these metallic masses have been found. On the statement of "two eminent tin smelters," Mr. Henwood says, "The entire county now yields only about 50 tons of stream tin in a year." This may be perfectly correct so far as the natural deposits of the valleys are concerned, but the following quantities of black tin were obtained in 1881 from rivers and beaches,—the deposits being derived to a great extent from the neighbouring mines,—the 909 tons given, being principally gathered from the loss suffered in the process of "dressing" the 11,944 tons of black tin obtained from the neighbourhood of Camborne and Redruth. When the preparation of tin ores for the smelter becomes the subject of comment, this loss, equal in money value to £36,169, will be again referred to.

BLACK TIN OBTAINED FROM STREAMS, RIVERS, AND FORESHORES, 1881.

Names of Streams.	Quantities. Tons.	cwts.	qrs.	Values. £	s.	d.
Red River, Dressed Ore, Tin Roughs, &c., from Carn-Brea District	909	1	1	35,283	0	0
Lelant Stream	6	19	1	267	19	8
Clegger Porth	0	7	0	15	2	3
Goonlaze and Ty Tyas	0	5	0	12	15	8
Helston Stream	1	16	3	88	0	10
Letcha Foreshore	0	13	3	38	4	0
Spit Beach*	20	0	0	8	0	0
Short Horn Beach	6	1	2	167	13	11
Crinnis Beach	3	15	3	70	4	0
Trevaunance Beach	2	5	3	114	4	4
Trevellas Beach	0	11	1	24	6	9
Tregonetha Common	0	2	3	6	16	6
Treworlis (Halvans)	4	0	0	63	14	0
Carbis Beach	1	1	0	9	13	9
Total	957			36,169	15	8

The examples which have been given will sufficiently serve to prove that the black tin found in the lodes or veins may have been derived from the

* Sand containing but little black tin.

rocks in which it has been shown that tin exists as a constituent element. Water containing mineral, or organic acids, may have acted as the solvent and agent, and then have parted with the mineral salts in solution in passing through the fissures of the rocks, or in filtration, through rocks which are more or less porous.

When we examine the evidences of vast mutations, which are the result of slow processes, continually in action through long periods of time, we can but arrive at the conclusion that not only the detrital tin, but much of that which is found in lodes, has been derived from this gradual disintegration of the older rocks. The conditions prevailing in the districts of St. Agnes,—in the Granite region which is represented by the Ding Dong mine,—in the china-clay districts of Carclaze, and indeed of the neighbourhood of St. Austell generally,—clearly point to the superficial sources from which the vast quantities of detrital tin ore may have been derived.

The reverse of this picture must not, however, be neglected in the consideration of this subject. Dolcoath mine, near Camborne, has been worked for a very considerable time. In 1778 Pryce speaks of it as a mine which had been for a long period in active operation. He gives an engraving of *Bullen Garden* mine, worked, at that time, to a depth of about 110 fathoms, and says: "At a depth of from 50 to 60 fathoms is an aqueduct or level from Dolcoath mine, and there is a deeper level driving to the same mine at a greater depth." Therefore Dolcoath at that time must have been explored to a considerable depth. The only existing evidence which we possess is that given by Pryce, who shows two engine-houses, and these are supposed by the present thoughtful manager of Dolcoath mine to correspond with "what we now call Old Sump shaft, which is about 28 fathoms west of our present engine-shaft."

The Bullen Garden is called by Pryce a copper mine, and it was not, evidently, according to his description, identical with the present Dolcoath. He speaks of their drawing the water from the Dolcoath mine, and of their using a level to facilitate the drawing of mineral matter. Be this as it may, Dolcoath clearly commenced as a copper mine. "There was no doubt," says Captain Josiah Thomas, "a little tin in the 'gossan' on the back of the lode, but I do not think Dolcoath was worked as a tin mine in Pryce's time. We have raised some hundreds of tons of *gossan* in the last few years which produced about 20 lbs. of black tin per ton of stuff."

Certain it is, that subsequently Dolcoath was worked as a tin mine, when after many years copper reappeared in the same lode. Then, at a great depth, another change took place, and the mine is now worked as a tin mine. By what theory are these remarkable changes to be accounted for?

The following examples of the existence of copper ore as a constituent of the rocks are instructive, as proving the diffusion of cupreous minerals:—

Yellow copper ore is an ingredient in the Granite at *Wheal Vyvyan* mine, and in the Slate at *Wheal Music*. The ore is generally disseminated through the rock in a sort of random sprinkling. These segregations of copper ore *are not formed on lines* of regular bearing, but as nodules and irregular and unconnected masses dispersed through the rock. Mr. Henwood

informs us that "numerous examples of copper pyrites and vitreous copper ore dispersed in irregular and unconnected masses, and in minute veins through the Slate, occur at Taren Belwyd and Cae Mawr, near Dolgelly, in North Wales, and I have observed instances of both kinds *at the Parys mountain*, in Anglesea." *

The same conditions have been observed by the author in the neighbourhood of the *Drws-y-Coed* and *Symddc Dylluan* copper mines in Nantlle Vale, near Carnarvon, and he has been informed that similar deposits are to be seen in the vicinity of *Cwmdyll*, or the *Great Snowdon Mountain* copper mine, and at the Turf copper mine, near Dol-y-frwynog.

The conditions of copper ore and lead ore in the Sandstones of Cheshire, at Alderley Edge, and at other places already named, need only be referred to here as remarkable examples of the diffusion of metallic matter.

A similar deposit was worked at Eardiston, near West Felton, Salop, about twenty years since, and a section of the Limestone stratum and cupreous shale bed at Pant, near Oswestry, is noticed by Mr. D. C. Davies.†

In the Greenstones throughout Cornwall thin leaves of native copper are found in the small joints or cracks which occur in this rock.

LEAD, in the form of sulphide (*galena*), is very often found distributed in a crystalline form in the Slate and Limestone rocks. In Cornwall these isolated crystals are to be found in the Chiverton district, and curiously dispersed through the spathose iron lode, in the *Duchy and Peru* mine, in Perranzabula. The same kind of segregation is to be found in the lead districts of Liskeard and Menheniot, and also of Devonshire.

Williams‡ remarks: "Lead, copper, and other ores are found in the *composition* of the solid body of the rocks in many places. I saw a stupendous rock, at a place called Cwm-ystwith, in Cardiganshire, Wales, where so much lead ore was found blended in the rocks as to be worth working and separating from the rock. The rocks at Cwm-ystwith are of great height, and I saw the miners there suspended in ropes blasting down the rocks with gunpowder, and a number of busy hands breaking and knocking the compound ore small, in order to get it separated by washing and dressing." The same miner also writes: "One of the most remarkable rocks containing metallic ore in the composition of the stone is the breccia, or pudding-stone, at Gourock, near Greenock, in Scotland." "Both lead and copper are often found in Limestone quarries in several counties, and I have seen good lead and copper in Limestone in several parts of Scotland." He then enumerates the copper ore found at Currie, in the Lothians; at Kissern, in the Highlands of Ross-shire; and the brecciated rock at Lossiemouth, in Moray Frith. It is curious, after this satisfactory statement of observations carefully made, to find this author writing such a passage as the following: "I cannot help being persuaded that perfect metallic ores being found in the body and composition of regular Limestone and other solid rocks is not only an argu-

* "On the Metalliferous Deposits of Cornwall and Devon," p. 236.
† "Metalliferous Minerals and Mining," p. 136. By D. C. Davies.
‡ Williams, "The Natural History of the Mineral Kingdom," vol. i. p. 357. 1789.

ment but a *clear decisive proof* that the materials which formed the several ores and their intermixed and concomitant spars were poured into the veins and taken up in the composition of the strata when they were first formed."

A sufficient number of examples have been given to show that the ores of tin, copper, and lead are to be discovered in several varieties of rock, distributed in such a manner as to be fairly regarded as one of the constituents of the rock itself. These might be largely increased if it was thought necessary to do so. The dissemination of iron and manganese is so extensive that it is difficult to find a rock without the oxides of one or other of those metals. There appears indeed every reason for believing that if chemical investigations were carried on upon larger masses than those usually found in the laboratory, and with those refinements of research—with the aid of the spectroscope, which must be regarded as the triumph of modern chemistry—the presence of most of the minerals which are found accumulated in lodes would be detected. At present, however, we are only in a position to prove that Granite and Slate, with a few truly igneous rocks, contain tin and copper, lead and iron, in their composition, and that Limestone, and some of the Sandstone formations also, give evidence of the infiltration of lead and silver, cobalt and iron and manganese. But our knowledge, imperfect as it is, gives a shade of probable truth to the hypothesis, which accounts for the filling of fissures —the formation of lodes—by supposing that water penetrating the rocks dissolves infinitely small quantities of the metallic salts, and that these, by physical and chemical actions, become deposited as metallic ore in the fissures which have been previously formed to receive them.

The dissemination of metals, through certain rocks, is a subject upon which much has been said, but really very little done. Silver, lead, copper, and arsenic have been detected, either in sea water, or in the crusts formed inside the boilers of ocean steamers. In the deposits formed on the beds of the brine-pits of the salt works on the borders of the Mediterranean —which are black and slimy—copper has been constantly detected, as well as silver. Malaguti and Durocher have been very industrious observers of these facts.*

M. Boussingault, in vol. xlviii. "Annales de Chimie et de Physique," Third Series, October, 1856, has a paper on the same subject.

In a memoir contributed to the Academy of Sciences by Malaguti, Durocher, and Sarzeaud,† it was shown that silver is very generally spread through all minerals, and the great diffusion of this metal led them to make further researches as to its presence in sea water. This fact they clearly established; and, further, they consider that the metals lead, iron, zinc, and copper are held in solution in sea water as well. They have limited their researches, however, to silver, lead, and copper, for zinc was not found in such sensible quantities, and the presence of iron has been long established.

* See "Observations relative à la présence de l'argent dans l'eau de la mer." Par MM. Malaguti et Durocher. ("Comptes-rendu," quarante-neuvième, 1859, p. 536.)

† MM. Malaguti, Durocher, et Sarzeaud, "Recherches sur la présence du plomb, du cuivre, et de l'argent dans l'eau de la mer, et sur l'existence du dernier métal dans les plantes et les êtres organisés." ("Annales de Chimie et de Physique," 3e Série, tome xxviii.)

If silver is found in salt water it must also be present in sea salt. The first experiments were, therefore, made on that substance, and silver was extracted, both by the wet method by means of sulphuretted hydrogen, and by the dry method by melting marine salt with pure litharge and pine-soot. Many experiments were well and carefully carried out, and it was proved that from even 100 grammes of rough marine salt, mixed with 25 of pure litharge and 1 of pine-soot, a very small button of silver might be obtained. Although these experiments proved the presence of silver in the salt of commerce, its existence in sea water might be produced by accidental causes; so, to avoid all doubt, these chemists directed their next researches on sea water carefully collected.

Many complicated experiments were made with undoubted success, and the presence of silver—pure and simple—in sea water was incontestably established, by the most simple method of precipitation by sulphuretted hydrogen.

The next experiments were on the seaweeds. It is well known how easily these plants assimilate iodine and other matters, and therefore it appeared probable that they would absorb silver. Large quantities of fucii of many kinds were dried and reduced to ashes, and silver was found in nearly all of them. If the presence of silver is admitted in salt water and in marine salt, it is clear that it must occur in many chemical products. Artificial carbonate of soda is found to contain more silver than sea salt. This is easily conceived when one thinks of the sulphuric acid and other matters that are used in its fabrication, this acid being itself argentiferous, as is also the nitric acid of commerce.

Experiments were next carried out on vegetables, and the blood of animals, with equal success, silver in small quantity being found diffused through each.

Rock-salt and coal were examined, and traces of silver were found in both, though the authors consider the presence of silver in coal as not yet sufficiently proved.

Having by a course of most carefully prepared and elaborate experiments established the fact of the presence of silver in vegetable and animal organisms, as well as in minerals, the authors of these researches next turned their attention to the discovery of lead and copper in the same substances. Many successful experiments were made on several kinds of fucus—lead and copper being constantly found. The authors remark: "The presence of copper in organic nature being a fact now generally admitted, one may conclude that if land plants draw this metal from the soil, the fucus also must draw it from the waters of the sea, that is to say, the element in which it lives." And they may justly conclude that if lead and copper accompany silver in sea water, the same thing probably occurs in all the economy of nature.

Although at first the presence of silver, copper, and lead in sea water seems singular, yet, say our authors, it is easy to comprehend when we remember how the sulphides of these metals are diffused through nature. The salt water attacks these sulphides and transforms them into chlorides, which are soon dissolved in the waters which circulate in the upper part of the Earth's

crust, and which nearly always contains chlorides and other alkaline salts. These act on the natural sulphides; they carry away from them small quantities of the metals which they hold in solution, and by that means they penetrate the tissues of plants, and also pass with food into animal nature.

Several German chemists have examined this subject and obtained similar results. We now know for certain that silver, lead, copper, and iron are widely disseminated. From these researches we can readily understand that from the vast reservoir of the ocean the metallic ore found in the rocks may have been derived. *Zinc* is mentioned as being found in quantities so small as to render its presence a little doubtful. The diffusion, however, of this mineral as sulphide, and carbonate of zinc, is proved by its existence in considerable quantities in the shallow deposits of the iron ores of Northamptonshire.

In 1880 a memoir appeared in the "Annales de Chimie et de Physique" showing that zinc existed, in a state of complete diffusion and in sensible quantity, in the primitive formations, and also in the sedimentary soils derived directly from them. M. Dieulafait * says there is no question that has been more disputed than the origin and the mode of formation of Dolomite. He does not now occupy himself with that question, but he brings forward a conclusion at which he has arrived after careful experiments. It is as follows: "The presence of bituminous matter in some Dolomites is an established fact; but beyond this, *the Dolomitic rocks constantly contain ammonia in proportions which have sometimes exceeded* 1 *gramme per cubic decimetre; that is to say, more than* 1 *kilogramme per cubic metre of rock.*"

This appears to be a reason for supposing that the Dolomites are not only sedimentary rocks in the ordinary sense of the word—that is to say, rocks of which all the elements are contemporaneous—but that they are produced in waters rich in organic matter. In a previous memoir it was shown that the concentration of *zinc* was effected even under our eyes in estuaries of a modern period. Following up these conclusions, and assisted by several well-known facts, such as the near kindred which exists between magnesium and zinc, the great analogy of their chemical combinations, and the isomorphism of their salts, it seemed probable to the author that zinc must exist in Dolomite deposits in sensible quantities. He made this the subject of his researches, and studied carefully in the four great Dolomite regions of France and Switzerland. He experimented on many samples from these places, and in all these he discovered zinc.

Without occupying ourselves with the origin of Dolomite, but taking only the chemical fact of the diffusion of zinc in the rocks, we arrive at one important result relative to the origin of minerals of zinc as they exist at present. It is this: minerals of zinc, particularly carbonate of zinc, are always in direct relation with the Dolomitic rocks. "It is on these slopes on the Mendip Hills, *composed of magnesian conglomerate* and of *Limestone of the same nature*, that the calamine mines are situated" (*Dufresnoy*).

* "Existence of Zinc in a State of Complete Diffusion in Dolomitic Soil." By M. Dieulafait. ("Comptes-rendu.")

In Belgium, at the Vieille-Montagne, "*calamine fills a depression in the Dolomite.*" In Silesia *the bed of calamine*, considered all together, makes a vast irregular mass; it is found in contact with the *muschelkalk*, sometimes covered by the Dolomite and sometimes in the Dolomite, branching in all directions. In the south of Europe the zinc mines of Sicily are as often in *Magnesian Limestone* as M. Lamarmora reports them to be in Silurian.

From these and many other examples it becomes apparent that minerals of zinc are contemporaneous with the Dolomitic Limestone in which they are enclosed; on the other hand, if the Dolomites of the Silurian system (Sicily), of the carboniferous soil (Belgium), of the muschelkalk (Silesia), and of other still more recent formations, in spite of their prodigious difference of age, enclose minerals of zinc of the same chemical composition and the same in all other details, it evidently shows that the same exceptional circumstances are active at very different epochs, to reproduce the same deposits.*

Mr. Frederick Field, on the 11th December, 1856, read a paper before the Royal Society "On the Existence of Silver in Sea Water." †

After referring to the researches of Malaguti and others, he states that a large vessel was hauled down in the Bay of Herradura, near Coquimbo, for the purpose of being repaired, when the captain furnished Mr. Field with a few ounces of the yellow metal from the bottom of the vessel. This brass sheathing had been exposed to the waters of the Pacific for more than seven years. The metal was found to be very brittle, and could be broken by the fingers with ease. Five thousand grains were dissolved in pure nitric acid and the solution diluted, a few drops of hydrochloric acid were added, and the precipitate allowed to subside for three days. A large quantity of white insoluble matter had collected at the bottom of the beaker and separated by filtration. This was fused with 100 grains of pure litharge and other suitable salt, the ashes of the filter being added. The resulting button of lead was subsequently cupelled, and yielded 2·01 grains of silver, or 1 lb. 1 oz. 2 dwts. 15 grs. troy per ton.

The captain of the *Nina*, a brig trading in the Pacific, gave Mr. Field a piece of Muntz's yellow metal from his cabin, from the same lot with which the brig was sheathed, but which had never been in contact with salt water, and also a portion from the hull of the ship after it had been at sea for nearly three years. The examination was made as before, the results being very striking:—

			Ozs.	dwts.	grs.	
1700 grs. from cabin gave ·051 grs.	= ·003 per cent.	=	0	19	14	per ton.
1700 grs. from hull ,, ·400 ,,	= ·023 ,,	=	7	13	1	,,

That which had been exposed to the sea having nearly eight times as much silver as the original sample. Several other results are given showing that

... ...at mercury is found in sea water. See also "Annales des Mines," 4e Série, t. xvii. p. ... "Note sur un composé naturel d'oxyde de zinc, d'oxide d'ammonium et d'eau." ("Compte-rendu," 1866, lxii. p. 413.)

† "Transactions of the Royal Society." ("Chemical Gazette," 1857, vol. xv. p. 93.)

copper immersed in sea water acquires silver considerably beyond that which it originally possessed.

Manganese is very generally diffused. Dieulafait finds the oxide in considerable quantities in the Dolomitic rocks.*

M. Boussingault ("Annales de Chimie" for November, 1882) publishes a paper "Sur l'Apparition des Manganèses a la surface des Roches," in which he shows that carbonic acid extracts the manganese from all sources and then deposits it on the rocks.

To recapitulate. It has been shown that *tin* has been found to be diffused through the rocks of the peculiar character which belong to Cornwall and Devon. *Copper* has even a more general diffusion over rocks dissimilar in character. In addition to the facts already given, it may here be stated that lead and copper (as at Alderley Edge) were found infiltrated amongst the Bunter conglomerate, through which the sinkings at Fair Oaks Colliery in Cannock Chase were made. At Fair Oaks the lead ore was within 29 feet of the surface; at Shore Hill the copper ore occurred about the middle of the 100-feet section. *Lead* has been found in the oceanic waters, and in the deposits in the boilers of steam-engines; *silver* has been found under several circumstances; *zinc* has been discovered in rocks of very dissimilar geological ages and in sea water; while *arsenic* and *antimony* have been detected by M. Daubrée in combustible minerals in various rocks and in sea water. *Gold* has not been named. There are no authorities of sufficient reliability who can be given as discoverers of this precious metal in the state of extreme diffusion. It is known to exist in connection with tin. It is also found to be in certain copper ores—those of Fowey Consols may be especially named. In the pyrites of Wicklow and other places, in some lead ores, and wherever quartz lodes abound, gold is generally stated to be present.

M. A. Daubrée,† in a memoir presented to the Academy of Sciences of Paris, has shown that a great number of little crystalline grains of a metallic grey colour, which he has observed in the Coal-measure Limestone of Villé (Bas-Rhin) are arsenical iron. He finds also in the coal, especially the two principal varieties, the same mineral in the proportion of 0·169 gr. and 0·415 gr. per kilogramme (about 2½ lbs. avoirdupois). Daubrée also traces arsenic in the coal of Saarbruck, in the lignites of Bouxwiller and of Lobsam (Bas-Rhin). Traces of copper were also discovered. He finds a proportion of arsenic in certain sedimentary beds, which derive their chief materials from eruptive rocks on the one hand, and the waters of the ocean on the other. In operating upon 100 grammes of the basalt of Kaiserstuhl he has recognised, he informs us, in this rock, in unmistakable quantities, both arsenic and antimony. Daubrée examined sea water and the deposits formed in boilers, and in both these minerals were detected. Arsenic, he remarks,

* "Le manganese dans les terrains dolomitiques. Origine de l'acide azotique qui existe souvent dans les bioxydes de manganese actuel." (Note de M. Dieulafait, présenté par M. Berthelot, Académie des Sciences, Séance, Jan. 8th, 1883, "Compte-rendu," tome xcvi. p. 125.)—"De manganese dans les eaux des mers actuelles et dans certains de leurs dépôts; conséquence relative à la craie blanche de la périod sécondaire." (Note de M. Dieulafait, présenté par M. Berthelot.) He finds, "Des eaux de la mer des Indes, de la mer Rouge, de la partie orientale de la Méditerranée, qui m'ont été rapportée par M. le Mécanicien, m'ont donné exactement les mêmes résultats."

† "Recherches sur la présence de l'arsenic et de l'antimoine dans les combustible minéraux, dans diverses roches et dans l'eau de la mer." ("Comptes-rendu Hebdomadaires des Séances de l'Académie des Sciences," tome xxxii. p. 287.)

is widely spread, not only in mineral veins but also in various rocks, where it is habitually accompanied by phosphorus, as was first shown by Professor Walchner. He then deals with the presence of phosphorus in the three kingdoms of nature. Sulphur, especially in the state of sulphate, is universally distributed.

Professor F. Sandberger* has arrived at the conclusion that the contents of lodes are in the main derived from minerals existing in the enclosing rocks. Veins of heavy spar may have received the barytes from felspars containing that earth, and so on. He attempts to prove the existence of valuable metals in silicates. Olivine always contains nickel and cobalt; and olivine from Nauroth, near Wiesbaden, contains 0·307 per cent. of oxide of nickel and 0·006 per cent. of oxide of cobalt. In the palæopicrite or olivine rock of Dittenburg, there is from 0·162 to 0·666 per cent. of oxide of nickel, which is further accompanied by copper, cobalt, and bismuth. In many varieties of hornblende Professor Sandberger has frequently found copper and cobalt. The same metals are often present in augite, and specimens of that mineral in diabase from Andreasberg afforded, in addition, lead, nickel, antimony, and arsenic. Mica obtained from graneiss and gnite has yielded most of the ordinary metals.

Professor Sandberger endeavours to show that the olivines, hornblendes, augites, and black micas of crystalline rocks of all periods contain heavy and noble metals. He points attention to the fact that lithia micas are probably the original source of tin which is found in the lodes, and he considers stannic acid may probably replace silica, as is already known to be the case with titanic acid.

We have, therefore, a considerable amount of evidence which proves that metalliferous minerals are extensively diffused over the surface of the Earth, and that they are to be detected in the waters which are constantly beating upon and wearing down the land. May we not, therefore, venture to suppose that the metallic ores found in the fissures of rocks are derived in a great measure from that reservoir of water which has existed since the Earth "was without form and void, and darkness was upon the face of the deep?" The geological evidence collected by reading the "sermons in stones" proves that districts now high above the present sea-level were at one time far beneath the waters. The sea must through all time, as it does at the present hour, have been filtering through the rocks over which it flowed.

The soluble contents of mine water are deserving of especial attention. Mr. J. A. Phillips has made most careful examinations of some of the waters infiltrated into the deep Cornish mines. Wheal Seton copper mine is situated about one mile north-east of the town of Camborne, in Cornwall, and is distant from the sea a little more than three miles. The workings of this mine are entirely in "Killas," or Clay-Slate, and the saline waters issue at the rate of fifty gallons per minute, at a temperature of 92° F. This has

* The following papers by Prof. F. Sandberger have been published: "Zur Theorie der Bildung der Erzgänge" [Theory of the Formation of Lodes] ("Berg- und Hütten.-Zeitung," 1877, xxxv. pp. 377, 389); "Ueber das Vorkommen des Zinnes in Silicaten" [On the Occurrence of Tin in Silicates] ("Berg- und Hütten.-Zeitung," 1878, xxxvii. p. 202); "Ueber die Bildung von Erzgängen mittelst Auslaugung der Nebengesteine" [On the Formation of Lodes by Solution from the Country Rocks] ("Berg- und Hütten.-Zeitung," 1880, xxxix. pp. 329, 337, 390, 402); "Untersuchungen über Erzgänge" [Researches on Mineral Lodes]. Wiesbaden: 1882.

intersected a fault, or cross-course, which can be traced in a northerly direction to the sea, the source beyond doubt from which this hot spring has been

MINERAL WATER FROM WHEAL SETON.

Solid matter 14·3658 grammes per litre, or 1005·61 grains per gallon. Sp. gr. 1·0123.

ANALYTICAL RESULTS.

——	Grains per Gallon.	
	I.	II.
Carbonic acid	5·56	5·50
Sulphuric acid	1·25	1·24
Silica	1·89	1·96
Chlorine	642·10	641·63
Bromine	trace	trace
Alumina	24·19	24·22
Ferric oxide	·22	·23
Manganese	trace	trace
Copper	minute trace	minute trace
Lime	243·56	244·74
Magnesia	5·05	4·97
Alkaline chlorides	454·44	452·38
Potassium	5·82	5·84
Cæsium	trace	trace
Sodium	160·84	160·19
Lithium	5·63	5·56
Ammonia	trace	trace
Nitric acid	,,	,,

derived. The working on the lode *a b*, Fig. 56, has been driven on to its point of intersection *b*, with the cross-course *f*, and is believed to have been thrown in a southerly direction from *b* to *c*. A dyke of porphyry, G H, 40 feet in width, courses parallel with the lode at a distance of a few fathoms to the north. The direction of the dip is indicated by an arrow. The water which issues from the point *w* was collected and brought to the surface in carefully cleaned stone-ware jars.

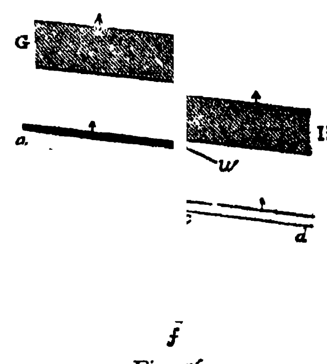


Fig. 56.

Mr. J. A. Phillips has also given analyses of the Elvan, Granite, and Clay-Slate rocks, but these do not appear to have much relation to the water. It is important, however, to give the conclusion to which this excellent observer has arrived:—

"*Source whence the Mineral Waters of Wheal Seton are probably derived.*—Before attempting to account for the presence of the mineral constituents found in these waters, it will be necessary to consider the bearing and importance of the following facts:—

"(*a.*) The average elevation of the surface of the mine is about 300 feet above the sea; and the 160-fathom level, being 960 feet below the adit or drainage-tunnel and 1,080 feet from the surface, is consequently much beneath low-water mark.

"(*b.*) The cross course, shown in the Geological Map, may, as has been already stated, be traced for a distance of three miles to the coast, and

apparently forms the channel through which the saline waters effect an entrance into the workings.

"(*c.*) The water contains a very large proportion of chloride of sodium.

"(*d.*) Similar springs of hot saline water were met with, below the level of the sea, in the neighbouring mines of North Roskear and North Crofty, and also recently at Cook's Kitchen, both situated on the same cross course. These waters have not been analysed.

"(*e.*) A hot spring yielding waters possessing the same general characteristics as those from Wheal Seton, formerly issued at the Wheal Clifford * mines in the 235-fathom level, or at a depth of 1,320 feet below the sea. It will be seen, by referring to a map, that in this case a well-defined cross course can be continuously traced in a north-westerly direction from the immediate vicinity of the spring to the sea at Tobban Cove."

The following remarks on Wheal Seton, by the same authority, are worthy of consideration:—

"It would be impossible to ascertain the precise conditions under which springs of this description have been produced; but the accompanying ideal sketch may perhaps assist in rendering intelligible what would appear, in the present state of our knowledge, a not improbable explanation of their origin.

"The plan A B C D (Fig. 57), being that of the cross course, is seen to

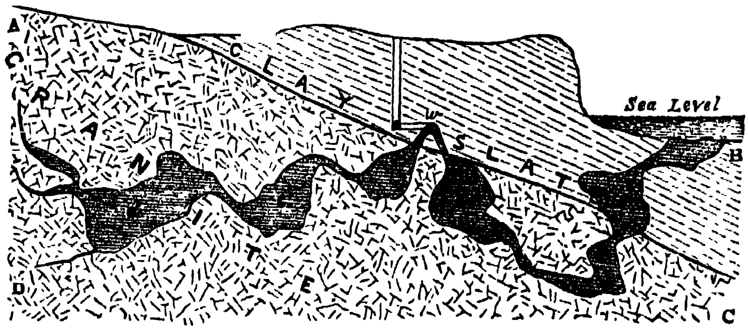


Fig. 57.

extend through both Granite and Clay-Slate to the sea. From the close contact of its surfaces, the presence of clay, and from other causes, this fault is supposed not to be uniformly permeable by water, which can only follow the circuitous passage, *a b c d.* In this way it penetrates to depths where

* Of the water of the Clifford Amalgamated mines the following analysis was given by the late Dr. W. A. Miller, and published as "Chemical Examination of a Hot Spring in Wheal Clifford, Cornwall," in the "Report of the Thirty-fourth Meeting of the British Association," &c., held at Bath, September, 1864. The waters issued at a temperature of 125° F., and at a rate of 150 gallons per minute.

Sp. gr. = 1·007. The saline constituents were found by evaporation to amount to 646·1 grains per imperial gallon, consisting of:—

Chloride of lithium	26·05
" potassium with a little chloride of cæsium	14·84
" sodium	363·61
" magnesium	8·86
" calcium	216·17
Sulphate of calcium	12·27
Silica	3·65
Oxides of iron, alumina, and manganese	minute quantity

reactions take place, which, although not entirely in accordance with the results of daily experience in our laboratories, can, after the investigations of M. Daubrée, M. de Sénarmont, and others, be readily understood.

"By the action of sea water on silicate of calcium, silicate of sodium and chloride of calcium may be produced. The sulphate of sodium of the sea water will be decomposed by the chloride of calcium, with the production of sulphate of calcium and chloride of sodium. The decomposition of clayey matter by common salt may produce chloride of aluminium and silicates of sodium, while the magnesium of the chloride of magnesium may be replaced by calcium; lastly, a portion of the potassium in the sea water appears to have been replaced by the lithium of the Granite."

All this points, of course, to the hypothesis, that veins are filled by saline water percolating through the more or less porous rocks, and slowly finding its way through the small fissures, and the larger cracks, which by various disturbances have been, through many ages, formed in the strata constituting the surface of our planet. This water may have been derived from the sea, which holds mineral matter in solution; or, it may have been merely the surface waters, charged with carbonic acid or atmospheric air, dissolving from the soil, soluble salts, which were again deposited by the operation of a force, acting from the surfaces of the fissures, which we have already called surface-force.

It is interesting to find Pryce saying*: "We may reasonably infer that water, in its passage through the Earth to the principal fissures, imbibes, together with the natural salts and acids, the mineral and metallic particles with which the different strata are impregnated, and, meeting in those fissures matters which have nearer affinities with the acid, of course disengage it, in whole or in part, from the metallic or mineral matter which it held dissolved, and which on being so disengaged by the natural attraction between its parts, form different ores more or less homogeneous, and more or less rich, according to the different mixtures which the acid had held dissolved and the nidus in which it is deposited. The acid, now impregnated with a new matter, passes on, till, meeting with some other convenient nidus, it lodges in that, and thereby acquires a fresh impregnation, perhaps at last totally unmetallic, or, for want of meeting with a proper nidus, appears at the surface weakly or strongly tinctured with those principles it had last imbibed."

Though this passage is of necessity marked by the chemical knowledge of the day, it shows that Pryce considered that the principal contents of veins—particularly the ores—might be introduced into the fissures by means of solutions which percolated through the enclosing rocks, and that then the various substances in solution arranged themselves in the fissures according to their affinities. He remarks on the occurrence of even small parts of lodes, containing several different kinds of ore, separated from each other by quartz, clay, and other substances, and asks how this could have been effected "but by the agency of water to bring, and the power of attraction to arrest, such and such particles, and deposit each in its proper matrix or nidus." He particularly notices the various kinds of lodes, as

* "Mineralogia Cornubiensis," 1778.

distinguished by the miners according to their contents, pointing out the difference between the *backs*, or upper parts, and the contents beneath. He describes a great variety of the *gossans*, observing that "the tender red gossan is very much inclined to produce copper ore, especially if the gossan be springy, cellular, and of a very red colour, like a well-burned brick. When it is thus, and spotted, and tinctured with green copper ore, like pieces of verdigris, it does not often deceive the proprietors. So likewise stones of blue or black copper ore, or of yellow ore having a black or purple outside, are very hopeful to follow when mixed in this gossan."

Pryce carries his opinion of the possible alteration of lodes so far as to suppose that they may even, in a few centuries, change their character so as to be rich at one time and poor at another; mineral substances being transferred from one part of the lode to another, "according to the solution and transmigration of their respective principles, which are deposited in some other magnetic nidus, whose power of retention in process of time may be again decayed, those principles again depart, and again be arrested *ad infinitum*." However little we may be disposed to agree with Pryce as to the time within which he supposes such changes can be produced, still we must allow him the credit due to the recognition of the possibility of change, caused by alterations of the conditions to which the contents of lodes may be exposed, an opinion considerably in advance of the views of his age.

Pryce was doubtless led to this remark from the prevailing idea amongst miners that a considerable period is required to effect the filling of a vein— a question about which there has been much misconception.

Dr. Fleitmann * has recently observed that the formation of mineral veins is far from taking so long a time as is generally supposed. About two years before writing he filled a ditch with common clay containing some iron. Having had occasion to dig this ditch anew, Dr. Fleitmann noticed, to his great surprise, that the clay had entirely changed its character and had become white. Moreover, it was divided in all directions by fissures, from the 25th to the 26th of an inch across, and these were filled with compact iron pyrites. He therefore supposes that the oxide of iron in the clay had been transformed into sulphate of iron, on coming in contact with water containing sulphate of ammonia.

A few simple experiments will prove that, under certain conditions, the deposition of metallic matter from solutions may be rapidly effected. The process of silvering glass by the action of some kinds of organic matter on a solution of nitrate of silver may be adduced. A little grape sugar or aldehyde being added to an argentiferous solution in a glass trough, pure silver is rapidly thrown down, and forms a film of perfectly white metal on the inner surface of the glass. If to a similar solution of silver, a minute quantity of the hyposulphite of soda be added, not sufficient to precipitate any silver, and the vessel containing it be placed in darkness, a film of black sulphide of silver will be slowly formed on the surface of the glass vessel containing it. This film is exceedingly coherent, requiring the action of an acid to effect its removal. Again, if a solution of sulphate of copper be placed in an unglazed earthenware vessel, the solution will gradually filter

* "Rapid Formation of Mineral Veins." By Dr. Fleitmann. ("Cosmos-les-Mondes." March 1883, p. 334.)

through it. Some crystals of the blue-stone solution will form on the outside and at intervals, after the action has gone on for some time, and the pores of the vessel become contracted by the deposition of some of the metallic salt, small fibres of native copper may be observed to form. The beautiful experiment of placing a stick of freshly-burnt charcoal in a solution of the nitrate of silver, and the formation upon it of the most delicate arborescent crystals of metallic silver, will be familiar to many. This is really only another example of the manner in which mineral veins are formed. These, it must be remembered, are not to be regarded as examples of the formation of mineral veins by the influence of electric currents, which will be presently referred to, but rather as evidences of the action of a peculiar force—not cohesion—which is by many delicate experiments proved to be active on all surfaces of solid bodies.

Werner, as we have already said, drew attention to the evidences o a system of regular deposits in mineral veins, that formed next the rock being the oldest.

M. Fournet,* and others, have observed that the extreme regularity noticed by Werner does not always take place, remarking that when the veins contain fragments of the adjacent rock imbedded in their mass, the ore has, in preference, always attached itself around them, enveloping them in a bed of greater or less thickness. Speaking of the regularity of the substances filling some fissures, M. Fournet mentions that M. D'Aubuisson notices a vein composed of differently-coloured beds of sulphate of barytes and fluate of lime, placed upon each other with so much symmetry in all parts, that more could not be accomplished with a compass and ruler. M. D'Aubuisson observes that this structure is exactly that which would have taken place if the fissure had been filled with a solution, successive deposits from which had been thrown down on its sides, adding that the section of some geodes, and some water-pipes, in which successive deposits have been effected, present analogous facts.

The same author has presented us with a very interesting account of the evidence which exists of the successive openings of the mineral veins in the environs of Pontgibaud, where for five years he was director of the mines. He shows that successive dislocations not only broke through the previously consolidated contents of the lode, but also that the complicated fractures frequently extended into the adjoining country, forming branches. Chemical deposits of different mineral substances, or modifications of such substances, are seen to characterise five of the six successive dislocations which M. Fournet has been enabled to trace in these lodes, the sixth being marked by the introduction of pebbles and sand from above, a continuation of that which still covered the country in many places, and which is itself covered by the lavas of the extinct volcanoes of Louchadière and Pranal. From this latter circumstance the author observes, that there would be nothing remarkable in finding the metalliferous veins cut or divided out by basaltic dykes, a fact that seems to have occurred in the veins of Courgoul and Saurier, on the south-east of the Monts Dorés. It further appears, that ferruginous and calcareous deposits are now effected in the open spaces which may present themselves in these veins, "so that, if after working out

* "Études sur les Dépôts Métallifères." (D'Aubuisson, "Traité de Géognosie," tome iii.)

the lode; the galleries be left shut during a long series of years, and the mass acquire a certain compactness from successive infiltrations, new workings could be carried on upon the siliciferous and calciferous hydrates of iron. The attle, or broken rubbish, is even found to be cemented by very compact ores of this kind, the mammillated surfaces of which have sometimes the same appearance as some of the hydrates of iron of old date."

The recent formation of *Pyromorphite* (phosphate of lead) has been already noticed, rarely, but occasionally, especially in the mines of Cumberland and of Scotland. *Mimetite* (a term derived from the Greek for *imitator*, this species so nearly resembling pyromorphite) is found coating other minerals. *Vanadinite* (so called from *vanades*, one of the synonyms of the Swedish Venus), vanadiate of lead, is constantly found amongst the *old heaps*, at the High-pirn of the Susannah mine, at Wanloch Head, on common and cupreous calamine, and sometimes on galena. Numerous other examples could be given of the comparatively recent formation of metallic minerals, many of them taking place on the surface, and under the eyes of the observer. One or two relating to copper will alone be mentioned. At St. Agnes, as at several other shipping ports in Cornwall, piles of copper were collected by the smelters in binns, and in the division appropriated by each firm the ore was often allowed to remain for a considerable period exposed to all atmospheric influences. Decomposition of the sulphide of copper slowly takes place, and this is washed out of the pile by the rain. This solution streams down the face of the cliff, and slowly, as evaporation goes on, under the changed condition a new mineral is formed. Flowing from the adit level at Perranporth, from Great Saint George's copper mine, copper water issues. This was at one time utilised by making it flow over scrap iron, and the copper precipitate was collected. Some dispute as to the property put an end to this process. The copper water flowed on over the soil and into the sand; the result has been the formation of oxides and carbonates of copper with other salts cementing the sandy particles together.

It has been already shown that even *attle*, or broken rubbish, has been found to be cemented with silicates and calciferous hydrates of the oxide of iron—another proof that the conditions which have been active from the beginning in producing those deposits, which we call *mineral veins or lodes*, are equally active at the present time.

Up to this point the influence of cold waters infiltrating the soil or percolating the rocks has alone been noticed. A short space must now be devoted to the formation of mineral lodes from the hot springs, which make the rock fissures their channels for pouring out their waters on the surface. There are no such examples in these islands, therefore the mineral lodes of America must furnish the required examples. With no actual knowledge of any mines beyond the United Kingdom, the author relies on the representations of those who have visited the mining districts of America and other places where hot springs are poured out in abundance. He is especially indebted to a paper by his friend Mr. J. A. Phillips,* from which the following extracts are taken:—

* "A Contribution to the History of Mineral Veins." By J. Arthur Phillips, F.R.S., F.G.S. (From the "Quarterly Journal of the Geological Society" for August, 1879.)

"Certain districts in California are remarkable for their hot springs; and in some of the counties included between the 38th and 40th parallels, and consequently north of the city of San Francisco, sources of this description are of such frequent occurrence that, when viewed from elevated ground, almost every valley is seen to be more or less occupied by wreaths of steam rising from a flow of highly heated waters.

"The vents giving issue to these heated waters usually evolve carbonic acid, which is frequently accompanied by various sulphurous gases; such waters are generally alkaline, containing carbonate and sulphate of sodium, as well as, occasionally, alkaline borates. They generally give rise to abundant local incrustations of either silica or calcite, usually more or less mixed with free sulphur. These deposits of sinter often extend, in nearly horizontal layers, to a considerable distance from the orifices from which the waters issue.

"When water is ejected from such vents in the form of steam and spray only, while gases are abundantly given off and large amounts of sulphur deposited, the aperture becomes a solfatara.

"One of the largest known deposits of sulphur in California occurs in Lake County, a mile beyond the ridge which bounds Borax Lake on its north-eastern side, and is many acres in extent. This 'Sulphur Bank,' as it is called, is composed of a much decomposed volcanic rock, traversed by numerous fissures, from which gases, steam, and water, either in the form of spray or of vapour, constantly issue; and upon and throughout the entire mass sulphur has been deposited in such large quantities that, at a short distance, the whole appears to consist of that substance. In the immediate neighbourhood of this solfatara are springs which give off carbonic acid, and of which the waters contain carbonates of sodium and of ammonium, chloride of sodium, borax, &c.

"In the year 1866 I visited Borax Lake and the neighbouring Sulphur Bank in company with Dr. R. Oxland, of Plymouth, who was the first to call attention to the presence of cinnabar in the sulphur from this locality; and in 1868 I published, in the 'Philosophical Magazine,' a paper advocating the probability of certain mineral deposits having been the result of hydrothermal or solfataric action.*

"For some years subsequent to my visit this solfatara was worked as a source of sulphur only; but during these operations so large an amount of cinnabar was discovered, both in the decomposed basaltic rock and in the cretaceous strata through which it has been erupted, as ultimately to lead to the opening up of the cooler portions of the Sulphur Bank as a mercury mine. This has long yielded large quantities of quicksilver, and affords a striking and instructive example of a recently-formed mineral deposit resulting from agencies still somewhat actively in operation." Mr. Phillips collected, not only specimens of this cinnabar, but also a specimen of a thin section of recently-formed quartz, from the face of a fissure in the decomposed basaltic rock.

"Many years since Dr. Oxland found a notable amount of silver in the

* "Notes on the Chemical Geology of the Gold-fields of California." By J. Arthur Phillips. ("Phil. Mag." 1868, vol. xxxvi. p. 321.)

sinter-like deposit from a hot spring in the county of Colusa; and Professor Whitney, previous to 1865, had been shown at Clear Lake some peculiar and interesting specimens of water-worn cinnabar, enclosing specks of gold, said to have been found near Sulphur Springs in the same county of Colusa.*

"Steamboat Springs, in the State of Nevada, are situated near the base of a volcanic hill seven miles, in a direct line, north-west of Virginia City and of the famous silver mines on the Great Comstock lode.

"The rock at this place is traversed by several parallel fissures, which either give issue to heated waters or simply throw off clouds of steam. The most active group of these crevices comprehends five parallel longitudinal openings extending, nearly in a straight line, for a distance exceeding a thousand yards; their general direction is nearly north and south, and all of them are included within a zone two hundred yards in width. These crevices are sometimes filled with boiling water, which overflows in the form of a rivulet; while at others violent ebullition is heard to be taking place at a short distance below the surface.

"These fissures are lined with a silicious incrustation, which is being constantly deposited, while a central longitudinal opening allows of the escape of gases, steam, and boiling water.

"The Great Comstock lode is, as before stated, situate in a volcanic district seven miles south-east of Steamboat Springs, has a nearly similar orientation, and is enclosed between walls of diorite on one side and of propylite on the other. This vein, of which the gangue is chiefly silicious—although calcite is also sometimes present—was first attacked by the miner in the year 1859, and since that time the mines worked have yielded silver and gold to the estimated value of above £60,000,000.

"The temperature of the waters issuing from mines worked upon the Comstock lode has always been somewhat high, but it was not until they had attained a very considerable depth below the surface that the workmen first became inconvenienced by extraordinary heat. At their present (1883) depth (2,660 feet) water issues from the rock at a temperature of 157° Fah. (70° C.); and, according to Dr. John A. Church, of Ohio,† who has recently published a valuable paper on the heat of the Comstock mines, at least 4,200,000 tons of water are now annually pumped from the workings, at a minimum temperature of 135° Fah. He also estimates that to elevate such a large volume of water, from the mean temperature of the atmosphere, to that which it attains in the mines, would require 47,700 tons of coal. In addition to this, however, 7,859 tons of coal would, he calculates, be required to supply the heat absorbed by the air, which passes along the various shafts and galleries through which it is diverted for the purpose of ventilation. It follows, therefore, that to develop the total amount of heat necessary to raise the water and air circulating in these mines, from the mean temperature of the atmosphere to that which they respectively attain, 55,560 tons of coal or 97,700 cords of firewood would be annually required."

The same author, in his work already referred to, gives a table of the

* "Geological Survey of California," vol. i. p. 92.

† "The Comstock Lode; its Formation and History." By John A. Church, G.M., Ph.D. New York: 1879.

temperatures of rock water and air, from which it is instructive to make a few extracts.

The temperature of the air at the surface varied, in June, 1877, from . 88 to 93 deg.

	Rock.		Air.
At 1,100 feet	128	„	112
2,000			108
2,135 „	—		106
2,200 „	139		110½
2,400 „	141		
2,480 „	152		
2,670 „	155		

He likewise remarks that "the rock is not uniformly heated throughout, but contains restricted areas, where the heat rises very much above or sinks below the temperature of the surrounding mass." Again: "These cold areas complete a well-linked chain of heat phenomena, extending from rocks that are sensibly cold to the touch, and may not have a temperature above 60° Fah., through rocks that have the average atmospheric temperature, and those which are as hot as surface rocks ever become in Nevada, to those which have a temperature of 157° Fah."

Dr. J. A. Church thus sums up the result of all his observation: "In brief, the phenomena of the Comstock lode do not admit even the possibility that the heat encountered is a remnant of ancient eruptive heat. That oxidation is not the cause of the heat is proved by inspection of the rocks." He refers the heat measured to *kaolinization*, "by which the anhydrous aluminic silicate of the feldspathic and amphibolic rocks . . . . is altered to Porcelain clay by combining with water. The water changes from the fluid to the solid condition, and in doing so, the general law of solidification is obeyed, the molecular motion which had maintained its state of fluidity becoming sensible as heat."

As attention has been drawn to a consideration of the heat of mineral deposits, and of the subterranean temperatures measured, this appears to be the proper place to give some attention to the thermometric measurements made, in some of our deep mines, in this country, the most important observations having been made in Cornwall.

Mr. R. W. Fox instituted a set of observations in the deep Cornish mines. The mean difference of temperature measured was as follows. The depth of constant mean average temperature was taken at 50 feet below the surface.

At 59	fathoms	below	the surface	the temperature was	60	deg. Fah.
132	„	„	„	„	70	„
239	„	„	„	„	80	„

This shows an increase of 10° at 59 fathoms, or of 1° in 35·4 feet; 10° more at 73 fathoms deeper, or 1° in 43·8 feet; and of 10° more at 114 fathoms still deeper, or 1° in every 64 feet of depth. With regard to those observations on temperature, although we get a general mean upon which some reliance can be placed, yet, in the state in which we find the returns at the present time, they are comparatively of but small value. We discover a general rate of increase of temperature with the depth, extending to the greatest depth observed, but we also discover irregularities resulting from local action. A very remarkable example of this is shown in the hot water flowing through the hot lode of the late Clifford Amalgamated mines. On a previous page (211)

will be found a section of this lode and the Elvan courses near it, to which the reader is referred (Fig. 22). One Elvan course comes to the surface, and is then about 1,000 feet from the mineral vein, and another comes also to the surface, and is seen about 250 feet on the other side. Three of these dykes come together and cut the lode, where the hot water flows out. These Elvan courses pass through the county for several miles, and send down a large quantity of water into the mine.

		Water.	Air.
The temperature	of the *eastern end* at the 224-fathom level was	110 deg. Fah. ..	71 deg.
Do.	,, ,, 235- ,,	108 ,, ..	81 ,,
Do.	bottom of Davey shaft	122 ,, ..	110 ,,
Do.	of the *western end* at the 280-fathom level	126 ,, ..	120 ,,
Do.	to the west of Garland's shaft at the same depth	128 ,, ..	118 ,,

That this high temperature was due to chemical influences going on in the proximity of the waterflow appears to be proved.

Some years since a mass of ochrey matter was sent to the author from a remote part of these mines, which was taken from 20 or 30 fathoms below the adit. A very large deposit had been discovered. It was found to be decomposed iron pyrites, and the water flowing through the Elvan courses derived its heat from the chemical action of the decomposing iron pyrites. The late Mr. Edward H. Hawke, one of the committee of those mines, wrote: "In the levels of Clifford Amalgamated mines the thermometer stood, as I have always heard, and fully believe, at about 100° Fah. *before the immense deposit of copper ore was taken away*, and now the same levels are cold enough to make the agent, when underground, wish for a great-coat in walking through them."

In 1864, Mr. Warington W. Smyth read, before the British Association at Plymouth, a paper "On the Thermal Water of the Clifford Amalgamated Mines." His remarks are so much to the point that it is thought desirable to quote them:—

"In the neighbourhood of Redruth, and situated mostly in the parish of Gwennap, is a district equally remarkable for the high temperature of its deep-mine workings, and for the enormous value of the copper ores extracted from them within the last half-century. The constituent rock of this region is mostly Clay-Slate or *Killas*, which, abutting against the Granite dome of Carn-Marth, dips away from that hill towards the east, and has not been unbottomed in the deepest mines .... although there can be no reasonable doubt that the Granite would be found occurring again beneath it. The Clay-Slate is intersected by dykes of Granitic porphyry coursing in an east and west direction; by lodes or mineral veins having, on the whole, a very similar line of strike; and by *cross courses* or non-metalliferous veins, running north and south."

Mr. W. W. Smyth then refers to Mr. W. J. Henwood's observations made in 1843, "On Subterranean Temperature in the Mines": "Thus at Poldice, about a mile north of the United mines,* and upon parallel lodes, the water flowing out of the lode at 184 fathoms or 1,104 feet deep, exhibited a maximum temperature of 100° Fah.; at the Consolidated mines, at 294 fathoms or 1,764 feet, the water in a level in the south vein was

* United mines and Consolidated mines were subsequently called Clifford Amalgamated mines.

95·5° Fah. At the United mines—in the western part or Poldory—a large gush of water from the Elvan course, at 184 fathoms or 1,104 feet, reached 90° Fah. In the eastern portion of the United mines, called 'Ale and Cakes,' a moderate spring flowing from the rock, between the great south lode and the old lode, at 195 fathoms deep, showed a temperature of 93·5°. A stream cut in the rock adjoining the great south lode in the eastern end, at 210 fathoms or 1,260 feet deep, was 92°.

"In the year 1839, a perpendicular shaft having been sunk to a greater depth than that at which the old lode of the United mines had hitherto been worked, a *cross-cut* was driven from it at the 180-fathom level (about 225 fathoms deep) which intersected the vein at a spot about a quarter of a mile farther west than the points at present in operation, and here a large feeder of water was encountered of so much higher temperature than had before been observed that it was at once termed a 'hot spring,' and the lode the '*hot lode.*'

"The shaft being deepened by successive stages, it has been found that at each deeper point at which the chief flow of water has been seen, it has been prevented by the excavations from rising farther upwards, and has shown a marked accession of temperature. In 1855 I found it welling up abundantly from a fissure extending along the north wall of the lode at about 1,510 feet from the surface, with a temperature of 114° Fah. . . . .. At present (1864) the bottom level, which, at the adit or datum line is 45 fathoms from the surface, is 275 fathoms or 1,650 feet deep; in its end the lode was narrow and very impervious to water, but a little rill trickling from it showed a temperature of 121°, whilst a larger feeder which fell from an upper working was 119° to 120° Fah. The next level above, called the 225-fathom level (below adit), is advanced farther eastward by some 70 fathoms; the lode exhibited a good breadth of fine black-coated copper pyrites, and small feeders of water issuing mostly from the north or hanging wall almost scalded the fingers holding the thermometers, which marked 122° Fah., whilst the air in the last few feet was 112° and loaded with vapour."

Mr. Smyth next informs us that "the amount of water delivered from the Clifford Spring is estimated at 150 gallons per minute. . . . . . As regards the increment of temperature, it is somewhat startling. Between my two last visits, made at intervals of nine years, on both of which I carried down trustworthy thermometers, the point of issue of the hottest water had been deepened 30 fathoms or 180 feet, and the temperature was increased by 8° Fah. This would give 1° for 22½ feet, whilst a comparison with Mr. Henwood's observation at Poldory would give a much higher rate. The same uniform rate of increase would bring us to the boiling-point of water at an additional depth of from 1,440 to 2,000 feet."

The evidence in favour of a *constant* increase of temperature with increase of depth does not appear to be at all satisfactory. All the high temperatures observed can evidently be accounted for by chemical decomposition of one kind or another. At the same time there is no doubt that the increment of heat in our deep mines points to a source of weak electrical action which does its work. Mr. Henwood* gives a long list of the observed temperatures

* "On the Temperature of the Mines of Cornwall and Devonshire," &c. By William Jory Henwood, F.R.S., &c., 1843.

of "the water as it issued from the unbroken rock." It is impossible to reprint those tables without sacrificing much valuable space. We content ourselves therefore with the following abstract:—

MEAN TEMPERATURES AT NEARLY EQUAL DEPTHS IN THE GRANITE AND SLATE ROCKS.

DEPTH.	GRANITE.		SLATE.	
	Depth.	Temp.	Depth.	Temp.
	Fathoms.	Deg.	Fathoms.	Deg.
Surface to 50 fathoms	25	52·67	30	55·9
50 to 100 fathoms	70	57·68	73	60·9
100 to 150 fathoms	132	65·0	125	68·14
150 to 200 fathoms	161	65·71	174	79·17
200 fathoms and beyond	240	70·15	241	89·4
Mean	94	60·35	116	68·89

No attempt to determine the difference between the mean temperature of the Granite and Slate at various depths was made before Mr. Henwood undertook the observations; he states that "the fact had been from time immemorial known to practical miners." It is familiar to miners that the largest streams of water flow through the *cross veins*—smaller ones through the lodes—whilst but little issues from the rocks, whether Granite or Slate. The working miners of Cornwall have long known that the tin lodes at equal depths are colder than those in which copper ores occur. Mr. Henwood furnishes also a table giving the

MEAN TEMPERATURE OF THE ROCKS, CROSS-VEINS, AND LODES AT NEARLY EQUAL DEPTHS.

DEPTH.	ROCKS.		CROSS-VEINS.		LODES.	
	Depth.	Temp.	Depth.	Temp.	Depth.	Temp.
	Fathoms.	Deg.	Fathoms.	Deg.	Fathoms.	Deg.
Surface to 50 fathoms	32	55·32	31	53·76	29	54·83
50 to 100 fathoms	70	60·2	76	61·2	71	59·87
100 to 150 fathoms	134	69·66	115	64·75	126	66·88
150 to 200 fathoms	180	82·11	163	74·4	161	72·41
200 fathoms and beyond	235	87·9	220	88·75	246	88·57
Mean	111	67·55	99	64·82	111	66·04

MEAN TEMPERATURES, AT NEARLY EQUAL DEPTHS, IN THE LODES WHICH CONTAIN ORES OF DIFFERENT METALS.

DEPTH.	TIN LODES.		COPPER AND TIN LODES UNITED.		COPPER LODE.	
	Depth.	Temp.	Depth.	Temp.	Depth.	Temp.
	Fathoms.	Deg.	Fathoms.	Deg.	Fathoms.	Deg.
Surface to 50 fathoms	27	53·14	33	55·06	32	56·9
50 to 100 fathoms	71	59·15	72	61·16	74	61·8
100 to 150 fathoms	129	65·92	124	66·09	127	68·39
150 to 200 fathoms	181	64·83	171	81·75	172	78·33
200 fathoms and beyond	230	74·3	—	—	244	89·14
Mean	92	60·69	74	61·45	140	72·39

We know not what the temperature may have been in the past ages when the lodes were in process of formation. The tables which have been given will not allow of our drawing any conclusions which bear on the formation of mineral lodes. They indeed prove little beyond the fact that there is general increase of temperature as we descend into the Earth, and that the increase is in a slowly diminishing ratio. We have already seen that the very high temperatures of the Comstock and other lodes in America is by Dr. J. A. Church referred to the conversion of felspar into kaolin. The decomposition of iron pyrites in the United mine, and those mines adjoining it, has been proved to be one source of heat. No support is given to the hypothesis of deep subterranean heat. As far as man has been enabled to measure the temperature, the only conclusion at which we can arrive is, that local causes alone are active in raising the temperature of the rocks. The measure of heat in Artesian wells is not satisfactory. The flowing of hot water from the deep borings, mixing with the cooled water of the upper portion of the bore-hole, leads to a modified result.

The well at Grenelle, where the temperature was observed by Arago, was at 1,794 English feet from the surface, and at 1,675 English feet below the sea-level, 82° Fah., or 1° in every 54·72 feet was measured.

For the well at New Salzwerk, in Westphalia, Humboldt gives the depth below the sea-level at 2,052 feet, and from the surface 2,285 feet; here the temperature was 91°, or an increase of 1° in 55 feet.

The well at Mondriff, in the Grand Duchy of Luxembourg, at a depth of 730 metres gave an increase of 1° in every 57 feet.

At Monkwearmouth, Professor J. Phillips gives the depth of 1,497 feet below the sea-level, and states the heat to increase 1° in every 59·36 feet.

At Duckinfield, Mr. Hopkins gives the result of an examination made to the depth of 1,330 feet, as showing an elevation of 1° in every 65 feet.

Mr. R. W. Fox gives the following as the result of observations made in three deep mines:—

Tingtang	630 feet	Temperature	68	deg. Fah.	= 1 in 2[illegible]
	1068	,,	82	,,	
Wheal Vor	834	,,	69	,,	
	1254	,,	79	,,	= 1 ,, 42
Poldice	864	,,	80	,,	= 1 ,, 12
	1056	,,	99	,,	= 1 ,, 21

The author has himself measured the temperature at the bottom of Tresavean 352 fathoms from the surface, in the sump 98°, in the Granite rock 100°. A remarkable condition presented itself in this mine which must not be allowed to escape attention. The copper lode in the Granite penetrated the rock very near its junction with the Clay-Slate, as a well-defined fissure lode, to the lowest level. Then the lode ceased to show well-defined walls, at about 310 fathoms below the adit, and the copper was disseminated through the Granite in a very singular way. The agent of the mine drew attention to a phenomenon observed by him. The Granite containing copper pyrites was at this depth exceedingly hard and coherent, so that much force was required to break it out. The broken masses being sent to the surface gradually cooled, and after a little exposure became so far changed that, with a slight blow, it fell to pieces. The cause of this

appeared to be the variations in the rate of cooling amongst the constituents of the rock. On placing some of the decrepitating pieces in an oven, and bringing them up again to a temperature of 100° Fah., they became as hard as they were in the bottom of the mine, clearly proving that the disintegration of the mass was due, mainly, if not entirely, to the amount of contraction produced in the copper ore and earthy crystals of the rock upon a loss of heat.

The composition of the water from a warm spring at Wheal Seton, supposed to be derived from the sea, has been determined by Mr. J. A. Phillips, and an analysis also, by the same chemist, of the hot water which issued from the bottom of Clifford Amalgamated mines, and which is exceedingly rich in lithium (see p. 368). The conclusion to which we arrive after what has been stated, is, that the heat detected in these waters is of local origin, and it will add to the interest of the inquiry if two other analyses of the waters of deep mines, made by Mr. Phillips, are given. The first of these was from the 212-fathom level in the Phœnix mine, near Liskeard, issuing at a temperature of 65° Fah.

WATER FROM PHŒNIX MINE.

Solid matter ·2130 gramme per litre, or 14·91 grains per gallon. Sp. gr. = 1·0002.

ANALYTICAL RESULTS.

—	Grains per gallon.	
	I.	II.
Carbonic acid	4·64	4·97
Sulphuric acid	3·07	3·01
Silica	2·13	2·17
Chlorine	1·64	1·58
Copper	·06	·06
Manganous oxide	·03	·03
Ferrous oxide	·29	·32
Lime	·99	1·02
Alkaline chlorides	11·49	11·33
Potassa	·90	·87
Soda	3·84	3·81
Ammonia	·01	·01
Nitric acid	·11	·11

The second water examined was collected at the 302-fathom level at Dolcoath mine, near Camborne, which formerly produced large quantities of copper ores. The Dolcoath lode has in depth gradually given place to tin ore, and it is at the present time the most productive tin mine in the United Kingdom. At the bottom of this celebrated mine a very remarkable change has been observed in the character of the rock. The Granite has become considerably softer, and less coherent, and at one place a layer of stratified rock, containing two very thin bands of black tin, has been opened out and traced for more than a hundred yards. This stratum assumes all the characters of a recently deposited bed, and might easily be mistaken for a new Oolitic formation. The water analysed was collected from the roof of a short cross-cut in Granite, 25 fathoms east of the engine-shaft and 15 feet south of the main lode. The water issued in considerable quantities, at a temperature of 92° Fah.; and a large portion of the upper parts of the vein had been removed by stopeing.

The following are the results obtained in grains per gallon:—

WATER FROM DOLCOATH.

Solid matter 46·97 grains per gallon. Sp. gr. = 1·0007.

ANALYTICAL RESULTS.

	Grains per gallon.	
	I.	II.
Carbonic acid	4·12	4·05
Sulphuric acid	9·13	9·06
Silica	2·06	2·11
Chlorine	13·34	13·34
Arsenic	trace	trace
Alumina	·03	·03
Ferric oxide	·31	·31
Manganous oxide	·04	·04
Copper	·05	·05
Lime	7·28	7·20
Magnesia	trace	trace
Alkaline chlorides	29·34	29·48
Potassium	1·92	1·93
Sodium	10·09	10·14
Lithium	trace	trace
Ammonia	·02	·02
Nitric acid	·12	·12

Pryce long since remarked that different jets of warm and cold water occur in some of the Cornish mines within short distances of each other. A remarkable instance of this has recently been observed in Cook's Kitchen mine, near Camborne. Mr. William Thomas favours us with the following account of those springs:—

"On testing the temperature at the bottom of the mine I found the thermometer to read several degrees higher than Captain Josiah Thomas's at Dolcoath. The air in our 345 end east was 90°. This end is 13 fathoms from a winze and 30 fathoms from shaft, as the following sketch (Fig. 58) shows: The water comes almost entirely from the bottom of the level, and I could not manage to separate the hottest water from the cooler. Placed in a running stream in the bottom the thermometer read, in two different places about 7 or 8 fathoms apart, between 94° and 95° Fah. Being in the same neighbourhood and acting on the same lode, at nearly the same depth as Dolcoath, there must be some special reason why the temperature varies so greatly. In sinking our last two lifts—say 25 fathoms—we have had a great change in the structure of the lode, consequent upon the junction of Chapple's and Dunkin's lodes at the 320. There appears to be a change in the character of the ground in many respects similar to that which has been described as existing at the bottom of the neighbouring ground at Dolcoath. It will be interesting to watch the progress of sinking in these mines, and to note the changes, if any, which occur as the depth from the surface increases. During the last two years the action of the water in the bottom of Cook's Kitchen has been

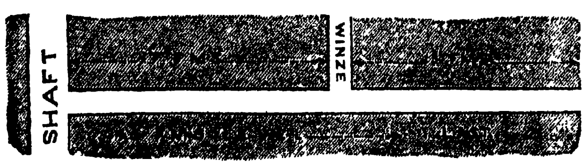


Fig. 58.

very interesting. A rough cross-section of the mine will show you more exactly than my words, and I therefore give the following figure:—

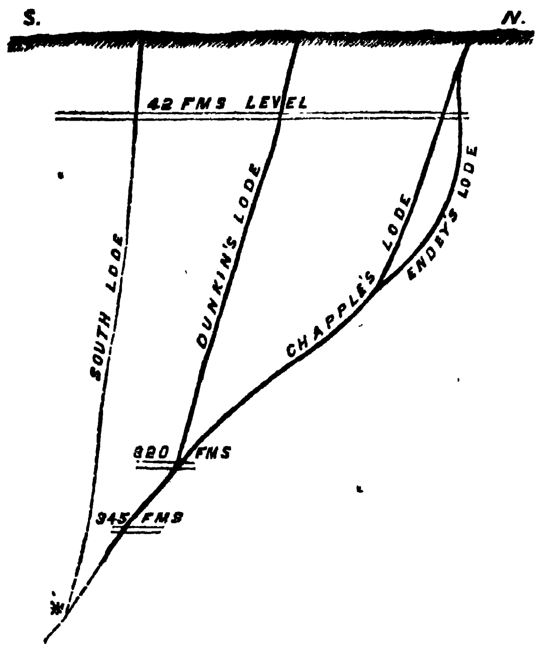


Fig. 59.

"The south lode has never been seen in this mine except at the 42, and we are now cross-cutting towards it at the 320, our present bottom being 345. I think the change of ground before referred to has enabled the water pent up in the south lode to find its way through a junction at a point up to the 345 on Chapple's and Dunkin's. The hot water comes from the bottom of this level. Hence we get a higher temperature than we ought, but this can only be temporary, for as the south lode is drained the temperature will naturally decrease. I believe that this mainly, if not wholly, accounts for the heat. The oxidation of freshly exposed mineral ground is said in some cases to cause an increased temperature. Our lode in the south part (the part driven on) is a very promising association of some 3 per cent. tin oxide with quartz and iron carbonate, also a little fluor, iron oxide, and 'prian.' So far as I can see there is nothing in the composition of the lode itself to cause increased heat by oxidation." *

It may not be quite apparent to some of our readers why so much consideration has been given to the increasing temperature of the Earth. This question is best answered by a quotation from De la Beche:—

"Upon the hypothesis that the heat at the bottom of fissures is supposed to be sufficient to *vaporise* water flowing into them, waters slowly oozing out of the pores and interstices of rocks into cracks, heated at their surface by the ascent of vapours close to them, would have a tendency to be vaporised before they could trickle downwards towards the more heated parts of the fissures. Consequently mineral substances which they held in solution, and which could not be carried in vapour with the steam at the same heat, would be deposited on the sides of the fissures."

Mr. R. W. Fox has observed respecting a fissure under these conditions: "The difference of temperature in the higher and lower parts of the crack would cause ascending and descending currents of water, and substances which are soluble at high temperatures, and insoluble when such temperatures are reduced, would be deposited as the water ascended and became gradually cooler." †

* Mr. William Thomas says in a subsequent note: "You have undoubtedly seen the report of Captain Josiah's recent observations on temperature in deep mines, making an increase of 1° for 98½ feet depth, as against 1° in 50 to 65 feet, as previously recorded."

† "Royal Cornwall Polytechnic Reports," No. 4, p. 108.

This hypothesis necessarily involves a much higher temperature than that indicated in the hot springs of the mines of this country. Some of the hot springs of California, as the quotations from Mr. J. A. Phillips, already given, have shown, certainly issue to the surface at high temperatures—157° Fah. to 135° Fah. are named. At such temperatures the water dissolves silicates, and these are deposited in the cracks through which it flows out to the surface. It is not improbable but that at remote periods similar conditions to those now found in America may have prevailed in this country, and may have been active in producing some of the conditions which we now discover in mineral lodes.

To obtain a fair approximation—with due allowance for modifying causes—to the rate of the increase of heat with the depth, in Cornwall and Devon, to those lines which mark curves of equal temperature beneath the Earth's surface, and to which Professor Bischof has given the name of *chthonisothermal*, would appear to be now the proper object of inquiry; one, however, which can be only accomplished with great care, for water rising up in the lodes, or percolating through the pores and crevices of the adjoining rocks, would always modify the temperature of particular portions of a mine.

Mr. Fox, in noticing the fact observed by Mr. Henwood and himself, that the Granite in the Cornish mines is found to be less warm at equal depths than the Slates, remarks that he had long attributed this difference to the facility afforded by lodes, as compared with rocks, and of Killas (Slates) as compared with Granite, for the ascending and descending currents of water.

The same authority considering that the high temperature of the lowest parts of deep mines is, in a great degree, independent of accidental or extraneous causes, not existing in the Earth itself, and that it is more often diminished by them than the reverse, caused thermometers to be placed at different depths in the rocks of Levant mine and in the Consolidated mines (Gwennap), the results of which were that the deeper thermometers (4 feet long) stood at a higher temperature than other thermometers placed near them and buried only 1 inch in the rock. In Levant mine the long thermometer in Granite, at 230 fathoms from the surface, and 200 beneath the level of the sea, stood at 80°, while the short thermometer rose only to 78·5°. Placed in Slate in the same mine at about 190 fathoms under the sea-level, and 4 feet from the lode, the former indicated 78° and the latter 72·5°. Results of a similar kind were obtained in Consolidated mines (Gwennap), with the additional information that, in a cross-cut in which the experiments were made, the temperature increased towards the lode, being in the latter much more considerable than in the cross-cut, an effect which Mr. Fox attributed to the greater facility afforded by it to the ascent of currents of hot water.

In Tresavean mine Captain Oates obtained the following results—experimenting at the request of Mr. Fox—with a thermometer buried 2 feet 10 inches in the rock, and another 1 inch under the surface of the rock at the two stations.*—

* "Report of some Experiments on the Electricity of Metallic Veins and the Temperature of Mines." ("Report of British Association for 1837," pp. 133-37.)

Depth in Fathoms from Surface.	Depth in Fathoms from Sea-level.		Experiments made In Air. deg.	In the Rock. No. 1. deg.	In the Rock. No. 2. deg.
26	—	In Granite 15 fathoms north of lode and 40 fathoms from "Killas"	53·3	57·	52·8
200	170	In the lode, rock do., "Killas" and three fathoms from Granite	77·2	76·	75·5
200	170	In do. 10 fathoms from do.	77·7	76·	75·5
250	196	In lode contained in Granite and 60 fathoms from "Killas"	83·2	82·5	82·
262	208	In lode, do., in 7 fathoms from do., being the bottom of the mine	85·5	82·5	82·

Sir Henry de la Beche supposes that fissures may have been opened beneath great bodies of water, as the sea, admitting a steady flow of that fluid through them. Under such conditions currents of ascending hot water, and descending cold water, would be produced; the steam formed would tend to rush upwards, and be converted into water when it arrived at temperatures less than the boiling-point of water. The fissures would tend to cooling by the entrance of cold water from above; but De la Beche then remarks: "It will be readily seen that under the conditions the rate of cooling would be so slow, that long periods of time would elapse before any material change would be effected in the temperature of the fissure, supposing even that the chemical effects which would be produced did not materially influence any changes of temperature that might arise." This eminent geologist says further: "We have abundant evidence whence to infer that, since the consolidation of the Granite and Elvan, and indeed of more recent rocks, the area under consideration was beneath the level of the sea, subject to oscillations that caused elevations and depressions, some of which may have been accompanied by dislocations of the rocks."

The whole of these hypotheses are based on the idea that there is a uniform increase of heat from the surface towards the centre of this planet. This assumption requires that, at a comparatively limited depth, the hardest of the known rocks must exist in a state of igneous fusion. The results obtained by the Astronomer Royal in the Harton Colliery* do not support this view. In May, 1826, Sir George Airy commenced his pendulum experiments for determining the mean density of the Earth at Dolcoath mine, in Cornwall, but sundry accidents prevented his obtaining a satisfactory result. Eventually, in 1854, new experiments were made in the Harton Colliery, and, with the advantages of using the electric telegraph, the most satisfactory results were obtained. The final results were:—

1211 feet of rocky and shaly beds gave a specific gravity	2·56
30 feet of coaly beds gave a specific gravity	1·43
Mean density of the Earth being proved to be	6·566

The value thus obtained was much larger than that obtained from the Schehallion experiment by Dr. Maskelyne, and considerably larger than the means found by the torsion-rod experiments of Baily.

When we remember that red hæmatite ore—the densest body in nature—is never of a higher specific gravity than 5·3, it appears to carry conviction

* "Account of Pendulum Experiments undertaken in the Harton Collieries for the purpose of determining the Mean Density of the Earth." By G. B. Airy, Astronomer-Royal. ("Philosophical Transactions of the Royal Society," vol. cxlvi. 1856.)

to the mind—seeing that none of the rocks which in our mining operations we have passed through approach to this specific gravity—that the centre of this planet must be a dense hard mass to give for the whole a specific gravity of 6·566.

M. Becquerel was the first to call attention to the influences of electricity in producing some very remarkable chemical changes in mineral bodies.* He remarks: "For a long time it could not be conceived how, with apparently feeble electrical forces, strong affinities could be overcome in order to decompose bodies and produce new combinations, it being considered that the action of currents more or less energetic should always be employed. As soon, however, as the electrical changes, which take place in chemical actions, had been analysed, it became clear that the same end might be obtained by employing weak voltaic currents. It can be readily understood, that when any voltaic couple be plunged into a solution, which reacts on one of the elements of this couple, the particles of the solution, the moment they are brought into play by the operation of chemical action, are then—since they are in a nascent state—in the most proper condition to obey the action of the electric current produced by the couple."

M. Becquerel produced a variety of crystalline substances, such as the oxides of many of the metals, and the sulphides of others, by the action of weak electric currents. He employed a tube, Fig. 60, bent like an U with a plug of moist clay, *a*, in the bottom, separating the solutions to be acted upon in the two branches *b c*, into which a wire, *d*, was introduced to form a voltaic circuit. The following was the form of one of his experiments: "Some clay, well divided and moistened with a solution of arseniate of potash, was placed in the bend of the tube. On the side *c* arseniate of potash was placed, and on the side *b* a solution of nitrate of copper. The latter penetrated readily into the clay; a very slow reaction took place between the arseniate and the nitrate, a circumstance favourable to the crystallization of the arseniate of copper. At the end of some time crystals resembling the arseniate of copper of nature were observed in some of the open parts of the clay." Many other examples of a similar change are given by M. Becquerel, showing the influence of weak electric currents in producing phenomena similar to those which we detect in our mines.

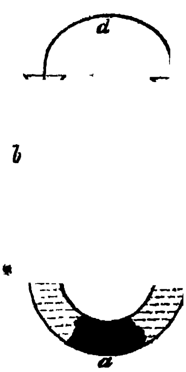


Fig. 60.

We have already alluded to the influence of electricity in laminating clay. It is now desirable to describe a very conclusive experiment, proving that miniature mineral lodes may be formed by the influence of this agency.

Masses of clay subjected to this action were found after some months to have assumed the conditions mentioned by Mr. R. W. Fox. On the side next the zinc plate of a voltaic pair distinct lines of cleavage, parallel to the sides of the clay and the plate, or at right angles to the direction of the current, presented themselves. These laminæ, on drying the mass, were gradually contorted, and at length broken off. On the side next the copper plate, instead of the laminated structure, a consolidation was observed of the

* "Traité Expérimental de l'Électricité et du Magnétisme," tome iii. Paris: 1835.

mass, this consolidation appearing to take place in the direction of the current, or very nearly so. The induration in many cases was very striking. In one experiment made with great care upon a lump of clay weighing several pounds, where the action was continued from July 4th, 1845, to January 20th, 1846, and then allowed to dry between the galvanic plates, the results were so curious as to merit particular description (Fig. 61).

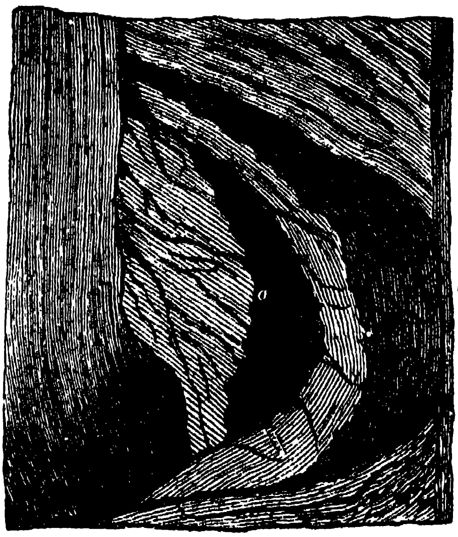


Fig. 61.—Electrical Experiment.

On the zinc side, z, to the depth of 1½ inch, there were distinct lines parallel to the plate, not extending from the top to the bottom of the mass, which was 12 inches deep, but after proceeding about 6 inches down exhibiting a tendency to bend inwards. Upon breaking the clay open when dry, it was found that after proceeding towards the centre of the mass, they again turned outwards, and formed indeed curved lines, from one point of the zinc plate near the middle, to its lowest point. The consolidation on the copper side C was very distinctly marked, and the appearance was that of a continuation of hard nodular masses along the lines of the voltaic current. This consolidation had evidently been produced by the drawing of particles from the centre of the mass, in which a large hollow, *a*, was formed; and this was found to be a portion of the very decidedly marked line of action from the bottom of the zinc plate to the centre of the copper plate C, and from that point again to the top of the zinc plate Z. As these curved lines approached the zinc side they were crossed and split by laminations, although very distinctly continued. We have thus evidence afforded us of two distinct forces in action, or perhaps it would be safer to say, indications of two lines of power, along which the particles arrange themselves. It was found upon close examination that the curved lines above described were formed by the metallic copper and the carbonate of copper and zinc (sulphate of copper was used on the side of the copper plate and muriate of soda on the zinc side). Upon breaking the clay transversely the appearance of the mass was in the highest degree interesting and instructive. From near the top on the zinc side a dark space was seen to describe a line inclining from the horizon at about the angle of 40°. When it approached the copper side it was gradually bent back, and formed a curve to the bottom of the zinc plate. This curve was formed, in parts near the copper plate, of laminæ of metallic copper, whilst more distant from it, specks of carbonate of copper appeared which were particularly confined to the marked space, and indeed represented an artificial mineral lode.

A difficulty at present exists, which will no doubt disappear when we have had the experience of further investigation. This is to account

for the arrangement of the particles of clay in parallel planes, according to the order of the diamagnetic curves, and, of the disposition of the metallic salts, and metal themselves, even of those which are not magnetic,—zinc and copper,—along what appears to be the true circuit of the electric current.

It was observed, very soon after the experiment just described was first established, that the fluid on one side was elevated considerably above the fluid on the other; this is the well-known *exosmose*, always observed during electro-chemical action. But in this case the mass of clay was elevated on the same side, and this went on increasing until the fluid was dried off. This may have been merely mechanical, but the fact is curious in itself, and worthy of notice, as it may lead to the explanation of some movements of solid matter under circumstances of apparent difficulty. Other experiments have proved to me the possibility of raising comparatively large masses of matter by the agency of current force, or the dynamic power of voltaic electricity.

A number of nodules were formed in the clay in this instance, and it was curious to observe, that all these concretions arranged themselves along the line of the current. In nature they are mostly found in some given direction parallel to each other; and, from the indications we have thus obtained, it is probable that we shall find their order determined by some local electrical influence.

A thin paste of plaster of Paris was placed between similar plates of zinc and copper, which were excited by diluted sulphuric acid. This action was kept up for about three months, and then allowed to dry off. On becoming quite dry, it was found that the gypsum was laminated, to the depth of an inch, on the zinc side and indurated considerably on the copper side.

An ordinary Bath brick used for scouring cutlery—a silicious Sandstone—was placed between a zinc and copper plate, in a similar voltaic arrangement to those already described, the current being excited by a solution of *salt* (muriate of soda) on the zinc side and sulphate of copper on the copper side. The lamination was very decided to the depth of more than half an inch, from which to the middle the brick remained unchanged, whilst on the copper side the general induration had taken place, as in the other examples. Copper had passed through the brick, and it presented itself in the form of carbonate on the zinc side, running across the lines of lamination. This brick had been placed in the trough vertically; it was only on one side that the carbonate of copper was seen, but it extended from a certain point near the centre of that side, increasing in quantity towards the zinc plate, no trace of it being seen on any part of the brick near the copper plate, except a thin lamina of it between the plate and the Sandstone. As the laminæ dried they became very much contorted, and were gradually broken off from the mass.

A similar brick was placed horizontally between a copper and a zinc plate, excited as before. After the action of about four months it was dried, when it was found to have cracked from near the bottom of the zinc plate to the top of the copper plate, separating into two nearly equal parts. This fracture corresponded in direction very nearly with that observed in the clay. On the zinc side the laminations extended to this line of fracture, and the consolidation on the other side was also stopped by it. Running from

end to end of the brick, about an inch within it on the zinc side, a line of carbonate of copper was traced, above and below which some traces of lamination were also marked out, as though this line of a metallic salt had become the centre of a new set of influences. At each end of the mass a great number of well-marked curved lines were observed, passing from the plates on either side to the fracture. This indication of a movement of the particles of the solid mass in determinate lines helps to explain the cause of the dislocation. The general tendency of the current being along these lines, lamination occurring on one side of the mass at right angles to them, and consolidation on the other in the line of the current, we can easily perceive that the line of dislocation must occur at a tangent to these curves at that point where the two influences neutralise each other, which will be found to be in a square mass from near one of its upper angles to one of its lower angles, the exertion of electrical force being evidently across the imperfect conductor, but in lines of greater or less curvature, according to the resistance its particles offer to the passage of the voltaic power.*

Cracks, or fissures, may therefore be produced by the action of weak electric currents, and then filled with metalliferous salts by the continuation of the same force. Mr. R. W. Fox's first experiment is very instructive. A basin was divided into two cells by a wall of clay. One cell was filled with a solution of sulphate of copper, the other with a solution of common salt. Into the copper solution was placed a piece of yellow copper ore (pyrites). The arrangement was allowed to stand undisturbed until all the fluid had evaporated. On breaking the wall of clay it was found that lines of metalliferous deposit had been formed in the wall of clay at nearly right angles to the direction of the electric current. The experiments which have been named appear to prove that electricity may perform a very active part in the filling of mineral lodes, and especially in producing the orderly deposition of mineral matter, which is not unfrequently found to occur.

The experiments of the laboratory clearly advance us many steps towards the confirmation of the view promulgated, viz. that by the agency of electricity, some of the conditions similar to those which prevail in rock fissures can be produced.

M. Becquerel considers that to a certain depth in the Earth a multitude of electric currents exist with very different directions, the general result of which would produce an action on the magnetic-needle. He considers these currents would be caused by the permanent communication, kept up by means of numerous fissures, through which the sea water percolates either to the metals of the earths, or alkalies, or to metallic chlorides, causing the metals to take negative electricity, and the steam and other vapours positive electricity. (It should be borne in mind that the difference in temperature observed between the surface, giving a mean of 60° Fah., and the temperature of such a mine as Clifford Amalgamated, with the heat at 120°, is quite sufficient to establish the electric currents alluded to by M. Becquerel.)

* "Researches on the Influence of Magnetism and Voltaic Electricity on Crystallization and other Conditions of Matter." By Robert Hunt, Keeper of Mining Records. ("Memoirs of the Geological Survey of Great Britain," vol. i. 1846.)

One part of the Earth's electricity, he infers, would be carried into the atmosphere by volcanic eruptions, and the other would tend to combine with the negative electricity of the base, by passing through all the conducting bodies which established the communication between the metals or their chlorides, and the solid, liquid, or gaseous substances which filled the fissures. Hence, he observes, a number of partial electrical currents would circulate in the interior of the globe, producing electro-chemical reactions, of which we cannot appreciate the whole extent, but which would certainly give rise to numerous compounds. It is not easy to determine exactly what M. Becquerel intends. It appears that he adopts the inference of M. Ampère that the direction of the terrestrial magnetic meridian is due to the circulation of electricity from east to west around the globe. It, in fact, amounts to this. The Earth advancing to meet the sun feels, upon any given point, the influence of the bundle of forces tied together in the solar ray—light, heat, electricity, actinism, or chemical power—which produces a current of electrical force, as we usually call it, but strictly speaking an *undulation*, flowing westward from that point. Therefore a stream of electrical force is constantly traversing this globe, from the east toward the west, and the magnetic bar of iron—called the compass-needle—in obedience to a fixed law, which compels it to place itself at right angles to such electrical currents, takes its true position of north and south.

The question now presents itself, Do we find in the mines any conditions similar to those by the agency of which chemical changes are brought about in the laboratory? At the same time as the French physicist was engaged in the experiments which have been named,* Mr. R. W. Fox, of Falmouth, who had published the experiment already referred to,—of making miniature mineral lodes in a basin,—was induced to inquire if such weak electric currents as he had employed in his artificial arrangement could be detected in the mineral lodes exposed in the operations of mining. All who were ever brought into close communion with Mr. Fox must have found in him an example of the true philosopher, who interrogated nature in the purest spirit, seeking only to elicit truth. Yet it is to be lamented that this gentleman was charged with having pirated from M. Becquerel's book on Electricity the facts now to be described, and with having appropriated them, without acknowledgment, as his own. Certainly Mr. Fox commenced his experiments with weak electrical currents without any information of what M. Becquerel had done, and it was only when he had established certain facts that he became acquainted with the results obtained by the French philosopher.

An hypothesis has been propounded that electric earth-currents select, in preference to any other course, the lines of conducting power, which are, it is supposed, constantly detected in mineral veins. It is, therefore, important to examine what has been effected towards the examination of this subject.

The existence of electric currents in mineral veins of copper and lead was first observed by Mr. Fox in 1830 †; but he could not detect their

* ...querel, "Traité Expérimentale de l'Électricité et du Magnétisme," tome iii. p. 295. Paris: 1835

† ...] Transactions," 1830.

presence in tin lodes, or in the earthy constituents of cross courses, or in the rocks which such lodes traverse. Magnetism was imparted to an iron bar by the influence of the current derived from a copper lode, passed through a helix of wire coiled around a soft piece of iron. In the same year this electrician discovered electric currents in the lead veins of Logylas and Frongoch mines in Cardiganshire, but he could not detect them in either the South Mold or in the Milwr mines in Flintshire.* In 1833 Captain Barnetts detected electricity in the copper lodes of Wheal Vyvyan.† In 1836-37 uncertain results were obtained by Mr. Fox in the lead veins of Middleton in Teesdale, Durham.‡ In the same year Mr. Pattison, at the request of the British Association, investigated the electrical condition of the Mountain Limestone and Sandstone of Alston Moor. The results obtained were, however, exceedingly uncertain.§

In 1833 Mr. Petherick appears to have detected electric currents in the copper lode of *Connorree*, in the Clay-Slate of Wicklow, Ireland.‖

In 1841 the author of this volume, with Mr. John Phillips, of Tuckingmill, Camborne, Cornwall, commenced a set of observations in the deep mines around that town. The results were from time to time published in the "Reports of the Royal Cornwall Polytechnic Society," from which the following observations are copied :—

1. The whole of the researches included in this series were made in East Pool copper mine, about 70 fathoms below the surface, on two lodes, each underlying south, the north lode about 1 foot 6 inches in a fathom, and the south lode 1 foot in a fathom (*i.e.* where the experiments were conducted). The lodes, it may be remarked, are very irregular in their bearing and underlie, being most productive where they approach the nearest to the perpendicular. It is often observed in this mine that bunches of ore frequently lie between craggy walls, and Elvan is by no means considered an unfavourable indication.

In pursuing these investigations several sources of slight error were detected, which will be noticed as they occurred, in each set of experiments, it being a point of great importance to secure other observers from the inaccuracies to which they give rise.

2. The connection being made between the point 1 and the instrument at *a*, the other wire was carried along the level (Fig. 62). On being taken round the corner, marked 5 in the plan, the needle was deflected 15°, although no contact was made with the lode, and when contact was made in the north lode at 4, this deflection was arrested, the needle standing at 2°. This was soon found to arise from the wire being in contact with a pile of iron pyrites, 6, which giving out a positive current occasioned a deflection of the needle to the west. When this was prevented, and close contact was again made with the mass of ore at 3, the deflection of the needle indicated a current passing from west to east. The greatest deflection we succeeded in getting on this occasion was 45°. The interposition of plates of zinc or

* "Geological Transactions Royal Cornwall Geological Society."
† "London and Edinburgh Philosophical Magazine," 1833.
‡ "Reports of the British Association," vol. vi., 1838.
§ Ibid.
‖ "London and Edinburgh Philosophical Magazine," 1833.

of platina were found slightly to check the current, but never to change its direction.

3. Connection was made, and broken, between the wire and the lode to isochronous time, by the person producing contact, which not agreeing with the oscillations of the needle, produced variable intensities of deflection as aggravated or retarded by the difference in time of closing circuit.

4. Various points along the top or back of the level, between points *a* and 5, were next tried. It was found wherever the contact was made with ore that the needle was deflected as before, but no deflection could be excited by any contact with the rock. This was most satisfactorily determined, in proof of which may be quoted the remark of one of the miners who witnessed the experiment, "The little thing knows ore, but doesn't know the country."

5. The galvanometer was now fixed at the point *b*, and the permanent connection made still near the point 1, being a distance of about 15 fathoms; the large coil was connected as before with the point 4. The contact being made perfect at both ends, the needle of the galvanometer completed several entire revolutions, by the single impulse of the current passing from 1 through point 6 to point 4 and back to point 1, or from west to east. This being satisfactorily determined no further experiment was tried on this occasion, owing to the extremely bad state of the air in the mine.

6. The galvanometer—one having a heavy single needle, and consequently not very readily affected by feeble currents—was fixed at the point *c*, and the connection made with a large mass of copper ore at 3. It was noticed on this occasion that a deflection of 2° or 3° was produced between the *large coil of wire* in contact with the damp rock and the sulphuret of copper in the lode. To ascertain if the current was at all connected with the rock, the coil was placed on a damp board, when the deflection was found to be the same as before, clearly proving it to arise from the state of the metal considered in its electric relation to the ore. Contact was made by the large coil at 2, when the needle was deflected nearly 70°, but the direction of the current was now from east to west.* This, being contrary to the direction ascertained in former experiments, demanded the most rigorous investigation. The current was analysed by the plates of zinc and platina, but its direction still continued the same.

7. It was agreed that the observer should number aloud the oscillations of the needle, in such order that the even number should indicate the moment at which the needle arrived at its extreme deflection, raising or lowering his voice according to the amount deflected. The object of this was, that the person producing contact should make his own observations on the nature of the contact, which arrangement enabled him, first, to discover, that contact with the ore of the lode was followed by an elevation of voice, also that the presence of water, enveloping the end of the wire in connection with the ore, was productive of greater deflection, but had no effect when applied to the matrix of the lode or its sides.

8. Contact was made in many places along the cross course, between the

* Some time after this experiment was made, a large bunch of ore was discovered and worked out behind the point of contact. Whether the mass of ore had anything to do with the direction of the current was not proved.

north and south lode, without producing any deflection of the needle; but as soon as the wire touched the ore, in the south lode at 6 the needle was powerfully deflected in the direction, indicating a current flowing from west to east, as in the former experiments.

9. The connections were made exactly as on the last occasion, and the same results were produced, the direction of the current between the point 2 in the north lode and point 3 in the south lode being from east to west. The large coil was now connected with that portion of the north lode lying at the point 7 being carried round through the cross course, giving an extended length of wire about 22 fathoms. The deflections were now 90°, and the current from west to east, which is the greatest steady deflection yet obtained with the heavy needle.

10. The large galvanometer and wire being fixed as in the last experiment, the wire carried round to the eastern end of the lode and the connection made with point 7, the current was found to be in the same direction, from west to east. On this occasion the current was not allowed

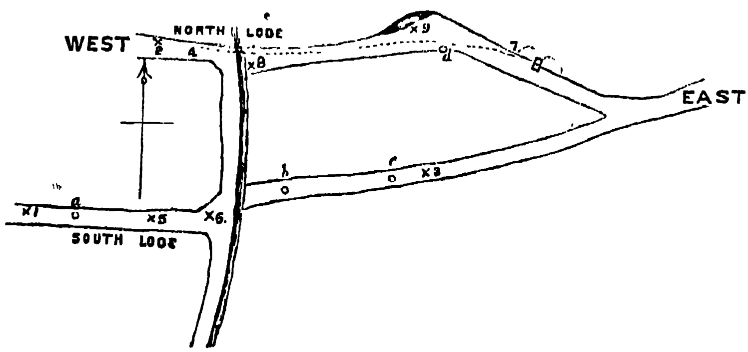


Fig. 62.—Electrical Experiment.

to flow through the whole of the wire on the coils, but small wires were attached by binding-screws, which completed by its connection with the galvanometer the electric circuit; this was found to increase the amount of deflection slightly.

We now decided, by a repetition of the experiments, that from all the points 1, 3, 4, 6, 7 the electric current was passing from west to east, but between the point 2 and any of the others, the currents appeared to take a different direction.

11. The large galvanometer was now fixed at *d* and the connection made at 7, and with the point at 2 the current was indicated as from east to west. Between the points 7 and the points 8 and 9 the current was evidently from west to east, as it was also between any other two parts of the two lodes tried at this time. It is not quite easy to explain the very peculiar local disturbance which was found to prevail in close proximity with the cross course at 2. But our experiments led us to the conclusion that the current in these lodes is constant from west to east, the deviation found at 2 being no doubt dependent upon some peculiarly local effect.

Being desirous of endeavouring to effect chemical decomposition by the agency of the electric currents flowing through the mineral lodes, we con-

nected two wires with the points 7 and 2, these being chosen from the convenience of their situation. The ends pointed with platina wire were placed in a phial which contained a solution of sulphate of copper. This being arranged was left in the mine for a few days. When the phial was next examined, one of the wires had been removed, no doubt by the curiosity of the miners, but the wire which remained in the phial was sufficiently coloured by copper, which convinced us we were not disappointed in our expectations. The experiments in East Pool mine have been several times repeated with the greatest care, but as the results have been invariably the same as those detailed, it is deemed unnecessary to recapitulate them.

Some experiments were afterwards made at Pennance mine by Mr. R. W. Fox, assisted by Mr. Joshua Fox. The following results, with which these gentlemen kindly favoured us, are added to those previously obtained:—

Pennance mine is in Killas. It consists of two lodes bearing nearly east and west (magnetic). One of these contains much arsenical and iron pyrites; the other is a quartz lode interspersed with oxide of tin and sulphides of copper and lead.

The more northerly lode, about 5 feet thick, dips a little towards the north; it has been worked 16 fathoms under the surface. The other lode has not been sunk deeper than 8 fathoms, 2 feet wide, and inclines towards the south.

All the experiments on the north lode gave currents through the apparatus from east to west, and so, indeed, did the experiments of the south lode, where they were tried, but they were less energetic.

In the east part of the north lode, at the six-fathom level, the current caused the needle to *revolve* quickly after producing and breaking contact a few times. Contact was made with the ore points by means of blocks and screws—by plates of copper, zinc, and platina in succession—and also by the points of the wires merely, but without any marked difference in the results under these different circumstances. Nor was there any great variation in the results, where the contact was made with different ores at the same station; thus the positive current was not less energetic where the contact was made with galena, as an ore point, than with iron pyrites nearly contiguous to it. All these facts show the independent nature of these currents, as it respects the apparatus, or accidental circumstances.

On connecting the back of the north lode immediately under the surface, containing arsenical pyrites, with a portion of the same lode farther west, in the six-fathom level, a maximum deflection of about 50° to 55° was produced with copper wire folded up, and pressed into a bundle for making contact with the ore points. There was a plate of zinc afterwards substituted for the copper wire at the surface, from whence the positive current was derived without any diminution of effect; and under these circumstances Mr. Fox was enabled to impart magnetism to a horseshoe bar of iron with several coils of copper wire round it, sufficient to act, though feebly, on a compass-needle, not very delicately poised. The stronger current below would doubtless have produced a much greater effect.

In 1830 Mr. W. J. Henwood commenced a series of observations, and continued them until 1840. "They extend," he says, "to every mining district within the Duchy of Cornwall except those of Helston and St. Austell."

After a most careful examination of all the results obtained we feel very reluctantly compelled to arrive at the following conclusions: In the first place, Mr. Henwood was not sufficiently acquainted with electrical science to carry out with accuracy a series of delicate observations on electricity. In the second place, the peculiar characteristics of his mind were such as to operate against his making satisfactory deductions from his experiments. His tabulated results are numerous, but they are vitiated by his incorrect system of examination. Frequently we find him establishing one pole of his arrangement with a plate of copper and the other with a plate of zinc, thus arranging a galvanic pair: from which electrical disturbance must have been produced, quite independent of any result obtained from the condition of the mineral vein.

This observer made some experiments on the influence of difference of temperature which are of great interest, and appear to be strictly reliable. The result of a long series of observations we find gives 57·1 per cent., from the warmer to the colder point, and 42·9 per cent. from the colder towards the warmer point. "We have," he says, "in the whole, thirty-three experiments, on points of different temperatures; and in 22, or 66·7 per cent., the currents have been towards the warmer, and in 11, or 33·3 per cent., towards the colder point."

The objections raised to the electrical hypothesis are supported by the following quotation. After the announcement of the discovery of electric currents in the metallic portions of certain lodes, Mr. Christie* remarked that some of the results might be due to the electric properties of the apparatus employed, an objection which had also occurred to M. Becquerel.† "The direction and quantities of electricity observed in rocks and veins are probably due to the plates of different metals employed." Von Strombeck entertained a similar opinion.‡ Professor Reich used sometimes only plates of copper, but occasionally he substituted a plate of zinc for one of them.§ Any one acquainted with the phenomena of voltaic electricity should know that if upon the surface of a damp rock a plate of copper is placed, and this is connected at some other point with a plate of zinc, electro-chemical change will be set up on the surface of the zinc, and a current be established through the wire, the circuit being completed along the moist surface of the rock itself. This is, it should be remembered, merely the local action of a single galvanic pair. The rocks themselves when *dry* are not conductors of electricity, but moisten them and they become conductors. The only reliable arrangement for determining the electricity of a mineral lode is to select a dislocated vein, to connect a clean copper wire with the ore on one side of the rupture, by boring a hole in it, and securing the wire by ramming in some powdered ore, and the other end of the wire, equally clean, in a similar manner with the ore on the other side of the cross course or *heave*, the two pieces of wire being connected through the galvanometer. If this arrangement is properly made, and if electricity circulates in the lode, its force may be measured off by the movement of the galvanometric needle.

* "Reports of the British Association," 1833.
† "Traité de l'Électricité," vol. v. p. 171. "Annals of Electricity," vol. ii.
‡ "Archiv für Mineralogie," vol. vi. § "Edinburgh New Philosophical Journal," 1839.

The result of the extensive series of experiments—carried out by the author and Mr. John Phillips—went to prove that no electricity could be detected in a copper or pyrites lode, unless it was to a greater or less extent undergoing decomposition. The electricity measured in these experiments gave the rate at which chemical change was going on in the lode. If lead lodes were decomposing, they indicated it by manifest electrical disturbance; but rarely could any electricity be detected in a tin lode, simply because the oxide of tin was not so liable to chemical change. In mundic lodes the currents were often very strong. At Pennance mine, as stated, an experiment was arranged between a pyrites and a copper lode, bringing the wires to the surface and dipping them into a solution of sulphate of copper. By this it was easy to obtain electrotype copies of medals; and ornamental articles, coated with plumbago or gold, could be perfectly copied by the direct action of the electricity derived from the lode. Electro-magnets could also be made by the current, and occasionally a faint spark obtained.

These results, and many others of an analogous character, must be regarded as the outshadowings of truths which are as yet but dimly seen on the clouds of speculation.

To summarise the various hypotheses which have from time to time been brought before the notice of the thinking miners. We find that Rösler, Becher, and Stahl, Henkel and Zimmermann, in some form or other, adopt the principles of the Stahlian philosophy which prevailed in Germany in the eighteenth century, when the alchemical dogmas were still holding in a somewhat altered form their place in the schools.

Von Oppel, who evidently originated the hypotheses accepted and expanded by Werner, Erkern, Feachsen, Gellert, and others up to the time of Bergman, took a more rational view of the "Science of Subterranean Geometry," which Werner attributes to Agricola. In 1778 we find Pryce adopting a reasonable theory as to the formation of fissures, and the filling of them, by fluids finding their way through them. In 1791 Werner promulgates his "New Theory of Mineral Veins," which has been very generally accepted; and this hypothesis modified by Bernhard Cotta may be regarded as the prevailing view at present entertained. The views of Fournet and of D'Aubuisson add to the ordinary views of Werner and Cotta as to successive openings of the fissures.* The latter, observes Necker, in 1833 introduced some new views; mainly regarding mineral veins as being immediately connected with unstratified rocks. The incompleteness of this view has been already shown.

In 1833 Mr. R. W. Fox drew attention to the influence of electricity in producing mineral veins. An endeavour has been made to show that a certain amount of truth belongs to this view, but that it does not account for many of the phenomena brought under notice. The views of Whitney in America and of Wallace in the north of England are both deserving of close attention. It, however, appears necessary, after this summary, to examine more closely than has hitherto been done the conditions supposed to have been active in the production of and the filling of veins.

There can be no getting away from the fact that metalliferous matter, in

* D'Aubuisson, "Traités de Géognosie," tome iii.

some form or other, must have been diffused through the rocks of the earliest formations. Of the condition of this—the earliest lithological condition—we know nothing, and it would therefore be idle to offer any speculations as to the state of the primary Earth. Sufficient, that we suppose the metallic constituents of the primary mass to have been broken up by convulsive throes, or, by the action of silent forces, operating on all matter. The smallest crystal of a metallic ore may form the nucleus about which a vast mass may, in course of time, accumulate. Such a mass, or myriads of such masses, may be strictly contemporaneous with the rock in which they may be discovered. If the action of water is admitted—and it is not supposed that the influence of a vast ocean can be denied—we have everything that is required to produce all the phenomena supposed to be due to *segregation*. Of this sufficient evidence has been already given. Mechanical forces operating upon the hardening rocks would naturally give rise to fissures. If the force acting as undulations in a given line is admitted, then we have all that is required for the production of fissured veins. By some force an immense number of cracks have been produced in one general direction. In the process of time another form of force, or a power acting in a different direction, gives rise to a newer set of fissures. It may be that the first set of fissures formed have been filled with metallic ores, or earthy minerals, before the second system of rents was produced. We have, therefore, by studying those phenomena, a means of determining the ages of the mineral veins so formed.

Supposing any of those veins to have been produced by the deposition of metallic ores from the water in which they were held in solution. It may be that the mineral solution has been the result of lateral infiltration, or of waters descending from the surface of the country dissolving out the soluble salts contained in the rocks through which it has filtered, or it may be that heated, or even cold, water has been forced from below, holding more metallic matter in solution. In either case the very condition of being forced through rocky cracks would be quite sufficient to cause some of the dissolved matter to precipitate on the sides of the fissure—the walls of the lode—and of course every change in the character of the solution would produce a change in the nature of the precipitate.

Sublimation—in the form, we will suppose, of sulphur or arsenical vapour—may bring up from the depths of the Earth matter which would be deposited on cooling. We have evidence of this action on the bricks of smelting furnaces, where very perfect crystals of pyrites are not unfrequently formed.

It is quite evident from what has been said, that electricity may and does act as a directing power, and that many of the conditions which are observed are due to electro-chemical influence.

CHAPTER IV.

REMARKABLE PHENOMENA OBSERVED IN METALLIFEROUS ORE DEPOSITS.

ALREADY, in dealing with the History of Mining, while giving examples of the methods adopted by the early miners in working out the mineral deposits discovered by them, some of the phenomena observed have been noticed. A few other interesting accounts of the mining operations, in several parts of the kingdom, remain to be noticed, and beyond this, it is desirable to direct further attention to the rarer phenomena of lodes, and to some of the more striking peculiarities of mining.

In 1671 a paper was read before the Royal Society entitled "Observations on the Mines of Cornwall and Devon." This informs us that up to that time a system of open workings prevailed in these counties. The ore and rubbish were raised by manual labour—being shovelled from *cast* to *cast*, or, as it was termed, from *shamble* to *shamble*. Thus in case of a lode continuing rich near the surface, a long chasm would gradually be formed. Chasms of this kind are not so numerous as they were fifty years since, but still many are to be found. These openings are called by the miners "*Coffens*." Mr. Carne states that the open work at Sealhole mine in St. Agnes extended nearly half a mile in length. At Polberro, in the same parish, a vast excavation of this kind was made. Similar openings were, a few years since, at Wheal Unity, Poldice in Gwennap, Wheal Vor in Breage, and at Godolphin. At Baldhu a *Coffen*, considerably over a mile in length, existed. At Drake Walls, in the east of Cornwall, was a very extensive excavation of a similar kind; it has, however, been nearly filled in, the miners being glad of any such reservoir for their waste material. In St. Just, at Trevagean, at Wheal Diamond, Bartinny Hill, Carnleskis, Wheal Dower, Fonthal Moor, and Praze, similar openings on the backs of lodes formerly existed. Mr. Carne gives the names of many others, as *Coffen Crista*, *Coffen Carharach*, *Coffen Garrow*, and the like. At the Bunny there still remains a chasm about 20 fathoms in length, and very nearly as wide. Similar evidences are to be traced at Botallack.

The mineral wealth accumulated within any given area—the rocks of which are known to be metalliferous—is limited so far as the superficial strata are concerned. We learn that some mineral veins cease to be productive in depth, while others continue to yield their treasures to the miner's industry to the greatest depth to which man has yet penetrated. Beyond this limit all is uncertainty, and probably the problem of the depth to which metalliferous ores may continue is insoluble. The increasing density of the Earth as we approach towards its centre certainly appears to indicate the presence of

very solid matter, which may possibly be of a metallic character. There are phenomena also connected with subterranean temperature, and possibly with terrestrial magnetism, which tend rather to support the hypothesis that a solid mineral mass exists in the lower zones. The question of an igneous centre is entirely beyond the point under consideration. With such speculations therefore it is not the purpose of this volume to deal. The subjects for especial consideration are—

First.—The depth to which minerals—the ores of the metals—may be profitably followed.

Second.—Is there evidence to support the hypothesis that thermal waters rise from any very great depth?

Third.—Are the contents of lodes or veins derived from the mineral springs flowing from great depths—from vapours sublimated from the abyss—or, are they deposits from waters percolating through the surface, or the rocks holding mineral matter?

Having examined the conditions of our knowledge and established, as far as facts will support our views, the known conditions regulating the dissemination of metallic and earthy minerals, we must proceed to inquire what minerals have been removed from the natural deposits of all descriptions, in the course of ages by human efforts, and what quantity of mineral wealth is probably remaining within the area of the British Isles, to reward the labours of man, aided by the ingenuity of his mind, and the engineering machines of his invention, enlarged by the increase of scientific knowledge, and by the powers of human reason. Attention must be invited, therefore, to the records of the *past*, a careful examination must be made into the conditions of the mining industries of the *present*, leading onward to careful deductions as to the probabilities of the *future*.

An idea very generally prevails that peculiar surface conditions, especially sterility, marks a productive mineral district. It has long been a common proverb, "A poor surface gives a rich soil." This, however, is true only to a certain limited extent.

In Cornwall, ranges of Granite hills covered with huge masses of "Moorstone" (Granite), heaped in fantastic forms, usually mark a mineral boundary. Gently undulating plains spread away from the bases of those hills, barren of vegetation, save the beautiful heath and the golden furze, which, when in full flower, give all the appearance of a garden to an otherwise waste country. These regions are commonly cut through by deep and often picturesque valleys, and within the shelter they afford, numerous plants, and especially shrubs, grow with a luxuriance not to be seen in any other part of England. On the hills and spreading over the plains, or, more strictly speaking, table-lands, are numerous tall chimneys, proclaiming to the stranger that he is in a mining district. These chimneys belong to the magnificent steam-engines which are employed in raising water from the deep mines, many of them pumping from 1,800 feet, and in one case as deep as 2,500 feet, and to the winding-engines by which the ores are raised, or to the crushing or stamping machinery by which they are prepared for sale.

Wherever *prosperous* mines exist the country has a dreary aspect. Waste-heaps—in many cases swollen into small mountains—are spread around, while

piles of mud, and pits of slime, gathered in irregular groups, indicate the processes of separating the metalliferous from the earthy portions of the ores. Consequently the whole character is, from either natural sources or artificial causes, rendered one of barrenness and waste. Still many of the mines of Cornwall are not without picturesque character and some beauty; while in Devonshire we find copper and lead mines in the very midst of thickly-wooded districts, spread along the margins of rivers which are of singular beauty; while, again, the mines which exist on the borders of Dartmoor partake of the general wildness of that moorland region, and the tin mines of this elevated district are to be found in localities marked by desolation reigning in savage grandeur, in solitudes the silence of which is only broken by the brawling of the winter torrents, or the roaring of the equinoctial tempests.

In Cardiganshire the mining district exhibits a roughly-featured, sometimes even corrugated, surface of hill and dale, which seldom rises into a bold peak, or breaks into precipitous hollows. Mr. W. W. Smyth, in his memoir "On the Mining District of Cardiganshire and Montgomeryshire," observes "that the neighbourhood of the mines, when at a moderate elevation above the sea, is rarely marked by that character of sterility generally observed in regions which are favoured in their subterranean treasures. The wanderer who pursues his winding way along the beautiful valley of the Rheidol, or traces up some of the many other streams, which flow east and west from the Plynlimmon range, is often struck with surprise to find himself, after a succession of purely rustic scenes, close to the mouth of a gallery, perhaps long ago abandoned, which opens in the midst of a wood of oaks, or upon a fertile meadow where the light tint of the conical 'burrow' or pile of excavated rubbish offers a marked contrast to the verdure of the surrounding landscape." The copper mines in the Vale of Nantlle, not far from Carnarvon, the mine of Cwmdyle, on the side of Snowdon, those mines which have been worked in the immediate neighbourhood of Bedgellert, and the numerous mines near Bettws-y-Coed, are in districts marked by features of peculiar wildness and rugged grandeur. The lead mines of Flintshire are distributed, some in spots distinguished by rural beauty, and others in an elevated country of the most uncultivated character. The copper mines of the Coniston district and the lead mines about Keswick are in the midst of scenes which delight the heart of the true lover of nature. Then, again, the mining district of Alston Moor, and of all that tract which extends across the country from Alston to Shotley Bridge, consists of high, massive, rounded elevations. "The hillsides in spring and autumn present a beautiful green surface, and in summer an abundant and flowery produce in the meadows; while on the same hill above the Limestone bare short grass, ling, and moss impart the brown and dreary aspect which characterises all the higher portion of the mining district" (*Sopwith*).

Descriptions of mining districts might be greatly, but not very profitably, extended. The sketches given will sufficiently prove that mineral treasures existing below the earth are rarely indicated by any peculiarities upon its surface. Of all the districts named—and to these might be added the dales of Durham and Yorkshire, with the picturesque valleys of Derbyshire—it may in,

general terms be said, that they present scenes varying from the sublime of precipitous rocks and rolling cataracts, to the calm and truly rural aspect of

Meadows studded with the herd and fold.

The luxuriance of a landscape does not indicate an absence of mineral wealth, neither does a barren country give any evidence of the existence of subterranean treasures.

The question, then, naturally arises, are there any natural indications to be discovered on the surface by which the existence of metalliferous ores beneath it may be inferred? Beyond the uncertain hypotheses—the result of untrained experience—which bids us regard one peculiar character of rock as being favourable—or, as the Cornish miner phrases it, "*being keenly*"—for ore, and to avoid another as exhibiting unkindly features, there are no guiding rules. There are apparently two *constants* which point to fixed laws, but these have not been followed to their ultimate conclusions.

1. There are evidences that the direction, as it regards the Earth's magnetic axis, has some connection with the metalliferous or non-metalliferous character of a lode. What form of force is in action to determine the deposition of a metallic, or an earthy mineral, in special parts of a fissure, remains a problem.

2. There are indications that, in many districts, the presence of two dissimilar rocks are necessary to the production of a rich vein of ore. There has been a disposition to regard these as a grand galvanic battery, but experiments do not favour this view. Probably a more careful examination of our mining districts may enable us eventually to quit the dangers of reasoning by analogy, and by a system of clear induction to advance to some general principles.

Beyond these we really possess but few, if any, guiding rules. The direction of the lode, and the necessity for the presence of two rocks having chemical or physical differences, indicate some apparent connection with electric or with magneto-electric phenomena.

As this subject is still under consideration, and will form the especial subject of an important volume—which is in progress—by that most competent authority, Mr. J. A. Phillips, it will occupy only so much space in this volume as will be sufficient to teach those who are unacquainted with the matter, of its importance and its interest. Connected with it are several other matters, having collateral bearings on this great question, which must come under our consideration.

During three thousand years, as tradition shows—by what may be regarded, by some, as shadowy evidence—and for at least two thousand years, —for which we have fairly reliable historical statements,—man has been with great industry seeking for buried treasure. When we contemplate this fact, we must become convinced that the exhaustion of the metalliferous deposits which originally existed in the superficial rocks which we call "the crust of the Earth" must have gone on to an enormous extent. It is important to determine approximately, *if we can*, the value of the minerals removed, and which can never be replaced, and thus to endeavour to arrive at some satisfactory conclusion,—if it be possible,—as to the prospects of the

miners of future ages in their exploration of the profounder depths, or of the unknown regions, of this planet.

It is not intended that a description of mines, generally, should be given in this chapter. But a selection will be made of such as possess some natural peculiarity, or are in any way remarkable, as mines, for the nature, or the extent, of the excavations which have been carried out. The author will attempt, as far as possible, to give examples which shall ensure a correct knowledge of the phenomena presented to the observer, in each of the various mining districts of the United Kingdom, and such as are peculiar to special geological formations.

St. Just Mines.—There is much which is curious and instructive in the mining district of St. Just. The accompanying copy from the map of the Geological Survey, Fig. 63 (which is drawn to the scale of one inch to the mile), will materially assist the reader: *aa* is a ridge of Greenstone rocks, which at Kenidjack Castle and some other places assumes much of a basaltic character—as do also some of the rocks around Cape Cornwall. The Slate is marked on the map as altered Devonian, but the evidences of alteration are not very satisfactory, and this band may be regarded as Killas — Clay-Slate — somewhat indurated. The rock within this, is a small portion of the great mass of Granite which extends to Penzance, St. Ives, and Lelant. All the black lines are mineral lodes, which coincide with the general direction of the joints in the rocks, being about south-east and north-west. The greater number of lodes are indicated on the map; most of them are short, and there are altogether between forty and fifty. The breadth of this important mining field is small, and but few of the lodes have been seen in more than one mine. The finer lines are cross courses, usually called in this district *guides*. The small veins, whether metalliferous or not, are designated by the St. Just miners, *scorrans*.

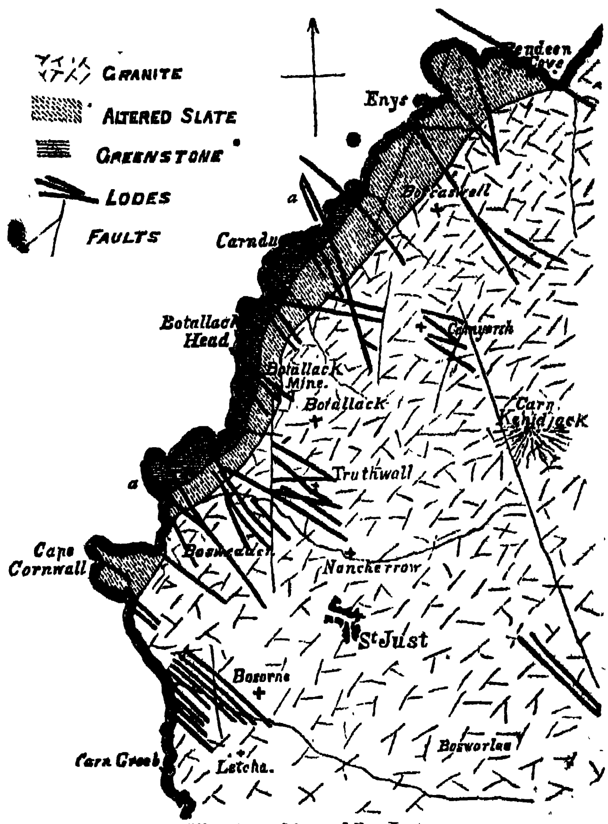


Fig. 63.—Map of St. Just.

are, as a rule, irregular. In many cases, although the lode

has continued rich in actual contact with the cross vein, it has never been discovered on the other side of it. This appears to indicate that the flow of fluid matter by which the lode has been filled was stopped by the cross vein. The difference in the size of the lodes has a remarkable effect on their productiveness. Where the lodes are productive, they are of fair average width, and where the size diminishes, they are usually impoverished. In every vein in the district the masses of metallic minerals have dipped *from* the Granite, or if occurring in that rock, they have inclined towards the Slate; in other words, the deeper portions of the ore have been farthest from the Granite (*Henwood*). It will be seen that several of the veins run under the bed of the Atlantic Ocean, and some of the mines are worked to a considerable extent under the sea. In 1778 Pryce wrote: "At Wheal Cock (a portion of Botallack) they have only a crust between them at most, and though in one place they have barely four feet of stratum to preserve them from the raging sea, yet they have rarely more than a dribble of salt water, which they occasionally stop out with oakum or clay inserted in the crannies through which it issues."

The same author gives the following account of the workings in this mine. "Wheal Cock," he says, "is wrought eighty fathoms in length under the sea beyond low-water mark, and the sea in some places is but three fathoms over the back of the workings; insomuch that the tinners underneath hear the break, flux, ebb, and reflux of every wave which upon the beach overhead may be said to have had the run of the Atlantic Ocean for many hundred leagues, and consequently are amazingly powerful and boisterous." Henwood, in 1831, writes: "At the cliff the level is 20 fathoms below high water, but the ore was worked to within nine feet of the sea at the time of my visit." This mine must evidently have been worked for a considerable time before 1778, seeing that at that time the level from Wheal Cock was worked 480 feet under the sea, and when the workings on this point were stopped they had advanced about 780 feet from the cliff. From Wheal Button shaft the length of the workings was still greater. They approached 1,950 feet when stopped at the depth of 115 fathoms, the deepest level, which was not driven quite so far, being 180 fathoms below the adit. In one part of Botallack the labourers have to descend to the adit by ladders placed on the face of the cliff.

The late Mr. Henry Curwen Salmon,* in an excellent article on "Mining, Quarrying, and Metallurgical Intelligence," written in 1862, thus describes the position at that time of Botallack, and some operations then in progress. As all this portion of the mine has been recently abandoned there is no possibility of obtaining equally correct information from any other source.

"Those who have visited Botallack may remember standing on the cliff, and looking down a distance of 250 feet upon an engine perched upon a ledge of rock, employed in winding from a shaft some little distance below that again. The shaft is called Pearce's whim shaft. To get to it you had to descend a winding path cut in the cliff called the 'Mules' Path,' from having been originally made for the use of mules to carry up the ore from the shaft to the dressing-floors above. This whim shaft has been sunk to a

* "Mining and Smelting Magazine."

depth of 180 fathoms; but at every succeeding level longer and longer drivings had to be extended from the shaft seaward, through unproductive ground, in order to reach the orey part of the lode, which dips away from the land. Thus at the 150-fathom level upwards of 200 fathoms of dead ground had to be gone through, and at the 180-fathom level 260 fathoms of dead ground. To pursue the shoot of ore further under such circumstances became impossible. In a mine working under ordinary circumstances the difficulty could have been met by sinking a new shaft down upon the orey ground; but as it was not possible to sink a shaft in the Atlantic Ocean, this resource was closed to Botallack. The lode was not to be readily abandoned, for it was a very rich one, having in one year between the 85 and 115 fathom levels yielded £24,000, and the ground above the 150-fathom level having yielded £50,000. At last it was determined to sink a new diagonal shaft from the surface, at such an angle that it should cut the productive part of the lode in the bottom levels. This was accomplished, the shaft being sunk 345 fathoms, cutting the 180-fathom level at a distance of 260 fathoms from Pearce's shaft. As the Crown lode is enclosed in hard Greenstone rock, it was found impracticable, except at enormous cost, to make the shaft larger than 6 feet square. This is of course a very small size for a shaft, and precludes the possibility of having more than a single waggon way. The waggon used for working on this incline holds about 16 cwt." The annexed woodcut, Fig. 64, gives a correct section

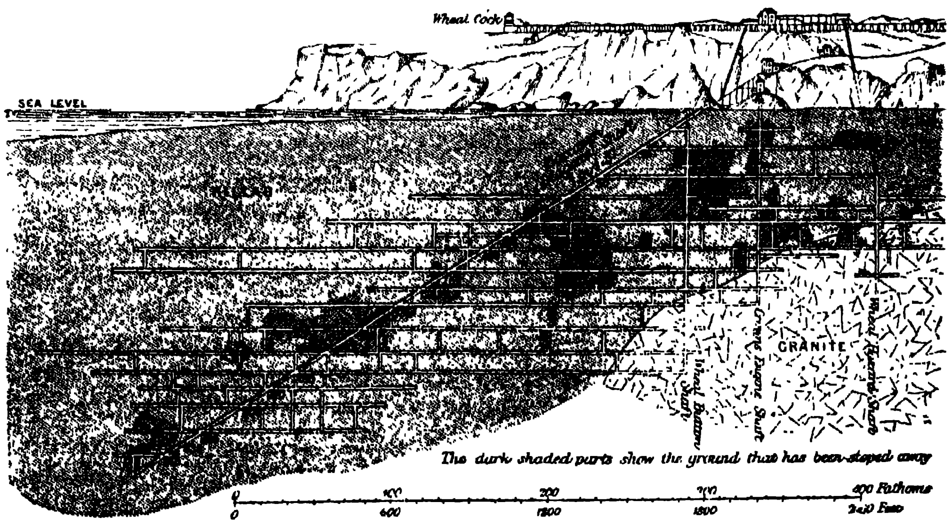


Fig. 64.—The inclined Shaft at Botallack Mine.

of that portion of Botallack mine which is under the Atlantic Ocean, with a representation of the diagonal shaft. It will be seen that the ore has been found nearly always in the Killas (Clay-Slate). The scale being given, the exact depth of the mine, and the extent of the workings, will be at once understood.

On the 18th May, 1863, a sad accident occurred on this inclined shaft, by which nine men perished.

This under-sea shaft, or rather plane, is sunk on the lode at a uniform

dip of 32½ degrees from the horizon, but with a varying direction, resulting from its following the course of the lode. In consequence of the hardness of the enclosing Greenstone rock this inclined plane is small, only allowing room for a single line of rails, which are carefully laid on transverse and longitudinal sleepers. The drawing is by waggons and chains, but the men are brought up in a special carriage called a "gig" made of iron, 6 feet 10 inches long, 2 feet 5 inches wide, and 1 foot 8 inches high, provided with four seats each arranged to hold two men, and also furnished with a safety-catch, partly self-acting and partly controlled by the men in the gig. The railway is completed to the 192-fathom level, but the shaft is sunk 17 fathoms deeper, and there is an opening of 2 feet 9 inches between the line of rails and the sollar at the 192. The men who were killed were being drawn from the 165-fathom level, and the gig had reached the 135-fathom level, when the chain parted near the surface, and the gig fell away to the bottom of the shaft. It does not seem to have left the rails as far as they continued, that is to the 192, where, passing under the sollar, it plunged into the lower and unfinished portion of the shaft. At the inquest, the verdict was "accidental death," the catastrophe being attributed to the carelessness, or want of presence of mind, on the part of the men in the gig in not bringing the safety-catch into operation. It is doubtful, however, whether under any circumstances men should be drawn up by chains, whatever precautions there may be adopted in the shape of safety-catches or breaks. The uncertainty of chains is proverbial; and in most other mines in Cornwall, where men are raised by skips, a wire rope with a double-linked connecting chain is adopted. The experience of every country in the matter of safety contrivances is, that while they usually answer perfectly on trial, they almost as usually fail when a breakage really occurs.

There are many remarkable conditions to be observed in Botallack mine, the occurrence of flat lodes being one of them. The whole tenement of Botallack is said to be full of *tin floors*. Gryll's Bunny is a name given to one of these, or rather to a number of small floors alternating with an ochraceous ironstone, to the depth of 10 fathoms. These floors dip 3 feet in a fathom to the north, and have been worked about 40 fathoms on their underlie, and as many on their line of bearing. The general produce is 150 lbs. of white tin in 100 sacks.* In this district we have that rare combination of tin and copper known as *Tin Pyrites*, which Dr. Henry S. Boase, M.D., discovered in 1822 in the mines of Botallack and Levant. This mineral has been rarely found, except at Wheal Rock (now West Kitty), St. Agnes, Wheal Scorrier in Gwennap, and Stenna-Gwyn, near St. Austell. It is composed of—

Copper	31	Sulphur	25
Tin	28	Silica and alumina	7
Iron	6	Loss	3

The lodes of Botallack and Levant contain this variety of tin ore in the vicinity of the cross courses; but when distant from them, the red ironstone becomes less abundant, and the tin and copper ores are for the most part

* "On the Stratified Deposits of Tin Stone, called Tin Floors," &c. By John Hawkins, Esq., F.R.S. ("Transactions of the Royal Geological Society of Cornwall, vol. ii. 1822.)

disseminated in chloride, containing also no inconsiderable portion of arsenical pyrites.

A lead mine in Perranzabula is another example of a mine which was also formerly wrought under the sea. The miners were sometimes sensible of a capillary stream of salt water, and, whenever they perceived it, they stopped it by filling the cracks with clay, as at Botallack.

St. Ives Consolidated Mines.—No mine in Western Cornwall presents so many remarkable features as this one does. The workings are, without doubt, of great antiquity. There are not wanting evidences to prove that the whole of the district from Halse Town to St. Ives was worked at a very early period. The present mine was, however, commenced in 1818, and it appears to have been started entirely for the purposes of a contested election. Before the passing of the Reform Bill the borough of St. Ives returned two members to Parliament. It will be readily understood that any industry giving employment to a large body of men would possess considerable influence in an election contest. This mine was commenced with but little hope of its becoming a valuable one. Employment was to be given to a certain number of men, who should become inhabitants of the borough, and be entitled to vote for the members of Parliament. It was originally started in 47 shares, which were successively increased to 94, 470, and 940.

The district which may be called the St. Ives and Lelant district demands a more careful study than it has yet received. Within it we have the St. Ives Consols, Rosewall Hill and Ransom United, with Goole-Pellas, Providence mines, Trelyon Consols, Wheal Margaret, Wheal Reeth, the group of mines now known as Wheal Sisters, and several others, which have been more or less productive, each one of them presenting some peculiarity either in the lodes discovered or in the rocks by which these lodes are enclosed. St. Ives Consols is a mine in Granite, although not far from the junction of that rock with the hornblendic schists and Greenstones, which come in immediately to the east, and indeed overlie the Granite in some of the eastern shafts. The mine lies immediately to the west of the town, and the principal lode traverses the bottom of the rather steep valley, through which passes the mountain stream that falls into the sea at St. Ives. This is called the Standard lode, and bears very nearly magnetic east and west—a little to the south of west—and is in many places nearly vertical. The Standard lode has been worked to the depth of nearly 200 fathoms. It is intersected by two principal cross courses or *trawns*,—as they are called in this district,—made up principally of decomposed Granitic matter.

The most remarkable feature, however, about St. Ives Consols was the extraordinary deposits of tin which were found to the south of the Standard lode, to which the name of *The Carbona* was given by the old miners. It is impossible in a moderate compass to give a very accurate idea of this stanniferous formation; but it is more analogous to the "pipe veins" and "flats" of the Limestone lead districts than to any other.*

The *carbona* branches off from the Standard lode. One carbona, called Lawry's, shoots off at the 57 level, dipping rapidly as it goes south, and forming stanniferous *flats* of various dimensions, which have been worked

* See description of "The Streek, Flat, or Dilated Vein," p. 288.

into a series of irregular caverns, wholly unlike ordinary Cornish mine workings. Another, or the *Great Carbona*—as it is called—goes off at the 77 level. At about 40 fathoms south of the Standard lode the level, which is driven on the western cross course, intersects what is called Kemp's lode, bearing nearly north and south, and which really seems to be a carbona branch. This lode is driven on for some way until it meets Noal's lode, and the *flats* and *pipes* coming down from Lawry's Carbona, at the junction of which, the whole opens out into one of the most remarkable deposits of tin ever found in Cornwall, the workings being excavated in enormous caverns 10 or 12 fathoms high and equally wide. All the dark spaces on the annexed woodcut (Fig. 65) represent the various cavities which have been worked out in different parts of the flat lode. The white lines are *levels* driven at the several depths named, in fathoms of 6 feet each. This will, therefore, give a correct idea of the extent of these vast excavations.

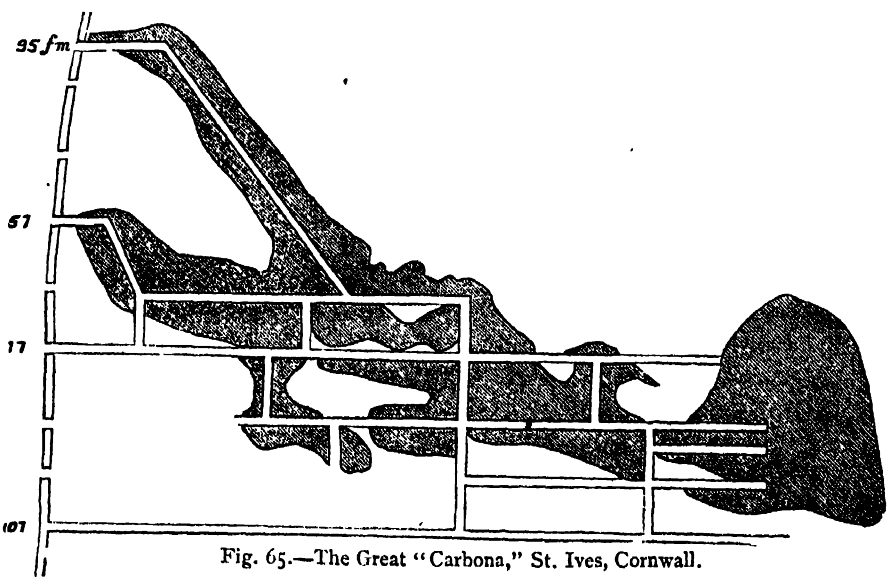


Fig. 65.—The Great "Carbona," St. Ives, Cornwall.

The term *carbona* is confined almost entirely to the St. Ives district, and several strange suggestions have been made, as to the source from which the name has been derived.* This can, however, be no longer doubtful. We find in the New Testament—published at the English College at Rheims, A.D. 1582,—in St. Matthew, chap. xxvii. v. 6, the following:—

"Principes, autem sacerdotum, acceptis argenteis dixerunt: Non licet eos mittere in *carbonam*:"

This in English becomes—

"But the chief priests having taken the pieces of silver, said: It is not lawful to put them into the *carbona*, because it is the price of blood." †

* The doubt which surrounded this term may be judged by the following note by the late Mr. H. C. Salmon, who was intimately acquainted with Cornwall: "There has been some discussion respecting the etymology of this word, which antiquaries of the old Celtic school have pretended to identify with an ancient Cornish word. There seems, however, no ground for this, and the word is probably an unaccountable corruption of some slang mining phrase." ("On the St. Ives and Lelant Tin-mining District.")

† The *carbona* was a place in the Temple where the people put in their gifts or offerings. It was, in fact, the treasury. Upon submitting the question as to the correctness of this definition to the Rev. Allen

It is a curious and not uninteresting fact to find the miners in Derbyshire applying the terms *vestry* and *treasury* to rich deposits of lead ore occurring in "flats" in the Limestone. The continuance of the term *carbona* from the time of the Phœnicians appears to be confirmatory of the traditions relating to their trading with Cornwall for tin.

In the *Providence* mines, near St. Ives, they have discovered similar flat lodes, to which the same term *carbona* has been given. The whole of these workings on the Great Carbona of St. Ives Consols were some years ago ruined by a fire which consumed the *stull*, or timberings (made of the largest timber procurable) that supported the workings, and which continued burning for six weeks, leaving the whole mass in irretrievable ruin. It must be understood that all these great *carbona deposits* were made about the *western cross course*, which afforded a convenient easement for the driving of the cross cuts, by which the tin stuff was brought back to the working shafts on the Standard lode. It is noticeable that all these *carbonas* form to the *south of* the Standard lode, and that when they near that lode they are generally small: indeed, looking at the matter in a large view, they seem to have been developed on an extensive scale by the contact of a series of approximately east and west lodes or branches, which range about 80 fathoms south of the Standard-lode with the converging cross courses.

The beginning of a *carbona* was seen in a level driving south-east at the 67, about 12 fathoms from the Standard lode. In the end there is a pipe, reaching about half-way up, surrounded entirely by Granite, and made up principally of Schorl, with some tin. The *carbonas*, when productive, are essentially characterised by a great development of Schorl.

The principal workings in the mine are about the eastern cross-course; their most striking feature is the immense width of the workings, often spreading upwards of 40 feet, although, when unproductive, the lode is scarcely traceable.

The surface of St. Ives Consols is divided into a remarkable number of small inclosures, belonging to different people. There are upwards of twenty lords of the freehold of this mine sett; and that a mine can be worked at all under such circumstances shows the excellent system of mutual conciliation which is so characteristic of Cornish landlords in the granting of mining setts. This mine commenced dividing profits in 1827, and between that period and 1862, £107,418 were paid in dividends to the shareholders. The early accounts of St. Ives Consols are lost, but we find that from 1835 to 1862 the quantity of black tin sold amounted in value to £478,030 15s.

The Flat Lode of Carn Brea Hill.—Extending from Wheal Uny to South Condurrow and Wheal Granville there exists a remarkable deposit of tin,

Vawdrey, vicar of Sithney, the following reply was received from that gentleman: "The term 'carbona' seems to be a well-known one by miners in this parish also, and is used by them to denote a piece of ground unusually rich in mineral. 'What sort of a load is a', Bill?' 'Haw, a beauty—a regular carbona.'

correctly, *Aramaic*, the language spoken by the Jews in the time of our Lord; and it certainly means a place very rich in good things, for it signifies the spot in the Temple where all the κορβᾶνς, or rich gifts and offerings, were placed. May not the use of this term in the county be a part of the proof that there were Jews in Cornwall?"

which is generally known as the *Great Flat lode*. This unusual formation has been studied by Dr. C. Le Neve Foster, who thus summarises his observations.*

"Their distinctive features are: (1.) The invariable presence of a small leader, generally only a few inches wide, apparently occupying the space due to the shifting of the two sides of a comparatively flattish fissure, and filled partly mechanically and partly chemically. (2.) A lode (or mass of stanniferous schorl rock), containing from 1 to 3 per cent. of *Cassiterite* from 4 to 15 feet in width, either above, below, or on both sides of the leader. The tin is distributed in little grains in the rock, or in strings, or minute veins. (3.) Schorl rock, poor in tin ore (locally called *capel, greyback, black granite, mother of tin*), separating the lode from the Granite and schorl rock, with its constituent minerals arranged in layers, also called *capel*, separating the lode from the Killas. (4.) Gradual passage of the schorl rock with lode on one side, and with Granite or Killas on the other; in other words, absence of any wall between the capel and the lode, or between the capel and the enclosing rocks."

Dr. Foster regards as new the fact of the lodes themselves consisting of schorl rock, "a point which has never before been made known." He then puts forward the idea that "the lode and capel are merely altered rocks, the fissure now occupied by the leader having served to bring up vapours or solutions capable of entirely changing the rocks on both sides of it." He in another paragraph says: "It must not be supposed the schorl rock is the only form of altered Granite. The conversion of Granite into '*greison*' is not uncommon, and Professor von Cotta † has given ample proof that the fine-grained, dark-coloured *Zwittergestein* has also been derived from the same source."

It has been previously remarked that the so-called *metamorphism* of rocks has been pushed to a severe extremity, and that the evidences of the alteration in the physical structure of Killas and Granite at their points of junction are frequently entirely wanting. Dr. Foster says: "Killas is often seen altered into a schorl rock, but here the two minerals *are disposed in layers*; sometimes it is schistose (tourmaline schist), at other times compact (*capel*)." The italics are marked to indicate that the layers would appear to show that the alteration has consisted not in a change of the Killas into schorl, but of a deposit of tourmaline in layers upon a deposit of Clay-Slate.

It is necessary here to describe briefly the *Flat lode* as it is seen in the workings of the different mines (Fig. 66). In the more eastern part of *Wheal Uny* the strike is 22° north of west, but to the west it goes south, and strikes west 37° south, and sometimes south-west. It dips about 46° south. At *South Carn Brea* the same lode has been followed between the Granite and the Killas for 175 fathoms. The course of the lode is generally about east 33° north, the dip about 35°. This mine was worked for both tin and copper.

West Wheal Basset was originally started to work a copper lode dipping

* "On the Great Flat Lode, south of Redruth and Camborne." By C. Le Neve Foster, F.G.S., &c. ("Quarterly Journal of the Geological Society," for August, 1878.)

† "Frestschrift zum hundertjährigen Jubiläum der Longil sächs." Bergakademie zu Frieburg. Dresden: 1866.

north, and eventually the *Great Flat lode* was intersected. The lode is now entirely in Granite. *South Wheal Frances* has the flat lode dipping from West Basset. It was intersected first at the 185-fathom level, and is known to exist also at the 205-fathom. The average dip is 32°, and the course about east 41° north. This lode is faulted by three or more lodes underlying north.

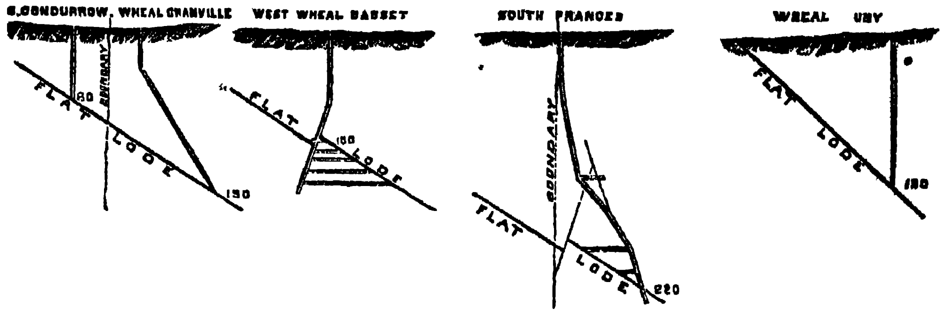


Fig. 66.—Sections of the Great Flat Lode on Carn Brea.

At *South Condurrow* and in *Wheal Granville* the *Great Flat lode* is entirely in Granite. The average bearing is about east 34° north, the dip 30° south.

The same authority has some remarks on the probable changes which have given rise to the flat lode. The following are of interest:—

"That Granite can be altered into schorl rock is a fact that can scarcely be questioned. Every china-clay pit affords us evidence of the fact. You constantly find little veins of quartz, or quartz and tin ore, bounded on each side by granular schorl rock, which is followed by Granite more or less decomposed. I have specimens in my possession of a passage-rock showing pseudomorphs of Gilbertite, after orthoclase, enclosed in schorl and quartz. The sharp walls of the quartz veins on the sides of the original fissures, and the absence of such walls between the Granite and the schorl rock, is what would be expected if the altering solutions gradually soaked in from the sides. Sometimes the schorl rock itself bears plain marks of its origin, as it contains numerous pseudomorphs of quartz after orthoclase. This is nowhere better seen, than in some rocks, occurring in the Granite near Penstruthal mine south of Redruth. The pseudomorphs are more than an inch long by ¼ inch wide, and are imbedded in a mass of schorl with a little quartz."*

The changes referred to in the Granite are seen in a striking manner at Wheal Coates, in St. Agnes, at Cligger Head, and in some of the china-clay works near Roche Rock, St. Austell. They are also well illustrated in the fine clay pits at Lee Moor, on Dartmoor. But the evidences in all these cases rather point to chemical changes produced by *natural ordinary* causes than to any alterations due to subterranean influences of a thermic character.

Dr. Foster supports his position by referring to the very remarkable deposits at Balmynheer, in Wendron, at Wheal Lovell, near Helston, and some other tin mines. His description of the South Wendron district deserves a careful study:—

* "On some Tin Lodes in the St. Agnes District." By C. Le Neve Foster. ("Transactions of the Royal Geological Society of Cornwall," vol. ix. part iii. 1877.)

"*East Wheal Lovell*, on the south-east, is worked upon a *pipe* of tin-bearing rock of a somewhat remarkable character (Fig. 67). The easiest way of giving an idea of it is to describe it as a very irregular cylindroid of stanniferous rock, A B, merging gradually on all sides into Granite, with its axis dipping at an angle of 49° from the horizon in a direction north 25° west (true). The longer axis of the oval section of the *pipe* varies from 20 to 60 feet in length, whilst the shorter is about 10 feet. The mass consists of quartz, mica, Gilbertite, a little iron pyrites, and tinstone, and is traversed by a few irregular joints. The southern part of the *pipe* is sometimes very

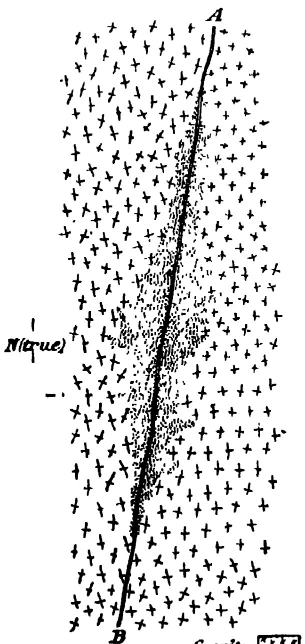


Fig. 67.—Plan of Deposit at East Wheal Lovell.

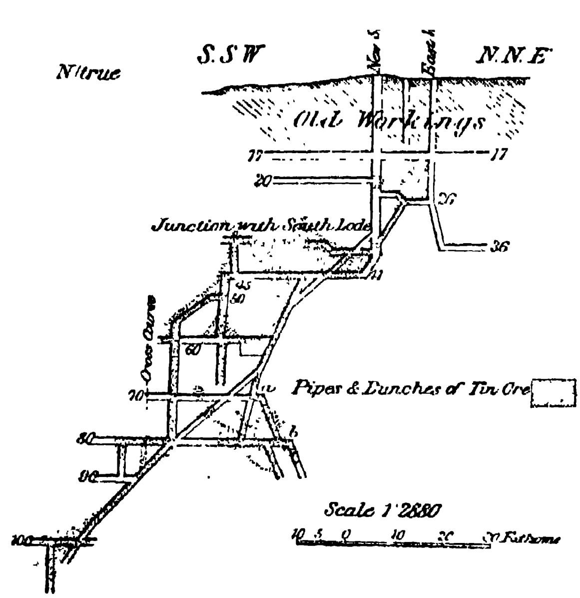


Fig. 68.—Section on the North Lode at East Wheal Lovell.

Granitic in appearance, and consists of pink orthoclase crystals imbedded in a mass of quartz, chlorite, mica, iron pyrites, a little copper pyrites, fluor, and tin ore. A glance at the section (Fig. 68) shows considerable irregularities in the shape of the several pipes and bunches, as might be expected from the shifting of an irregular fissure. The only difference between this and the carbonas of St. Ives is the absence of tourmaline.

The Valley of the Loe Pool.—Although the *stream-tin* or alluvial ore may have been first discovered, yet it is not probable that any long interval elapsed before the veins became also known as sources of this mineral, especially as it is often found that rich lodes crop up in the stream ground, the hard matrix having resisted the agencies that had degraded the rock containing it. This is particularly observable in the stream ground about Porkellis, in Wendron, where streaming and lode mining have been simultaneously carried on. Some of these outcrops have been subsequently explored to considerable depths at Wheal Foster, Porkellis United, Basset and Grylls,

and Wendron Consols mines, whence large quantities of tin have been extracted.

The valley of the Cober rivulet, in which these mines are situated, has been perhaps the most productive of alluvial tin ore of any in Cornwall; and it is somewhat remarkable that, while the stream works at Carnon, Pentuan, and the St. Erth valleys have been particularly described, this has remained comparatively unnoticed.

From its source among the Granite hills at Viscar, in Wendron parish, to its influx into the Loe Pool, the rivulet has a course of about five and a half miles. Near its source the alluvium is shallow and comparatively poor, though it has, apparently, all been turned over at some remote period. The underlying rock is coarse-grained, semi-decomposed Granite, traversed by hard dark blue veins, or "capel," containing patches of tin ore. In the neighbourhood of these veins the rock is often stained with oxide of iron. In places where some of these veins have been worked, it has been found that this coarse-grained rock extends to a depth of about twenty fathoms, when it becomes hard and glassy. The tin-bearing veins also become small, and the mining prospects altogether being such as have not been held to warrant very extended exploration. The tin ore is sparsely diffused in the soil and gravel on the hillsides, which also show traces of having been turned over extensively. Descending towards the village of Porkellis, the valley widens into an irregular basin, the bottom of which has been very productive of stream tin. The bed rock occurs at depths varying from six or seven to above twenty fathoms. In some places *false shelf* is met with, which on being broken through is found to cover a more ancient alluvium, which is generally rich in tin ore. Numerous veins traverse the "country," all of them more or less productive. On one set, still called "Balwath," or the "old mine," tradition reports that the first steam-engine in Cornwall was erected, the steam being raised by turf fuel. A little below this, near the village of Porkellis, the rivulet is joined by an affluent from the north, and about this place the valley widens considerably, and it was probably here that it has been most productive of tin. The whole bed has been repeatedly turned over, and operations on some parts are still continued. With great labour, a deep cutting has been brought up on one side, from about a mile down the valley, by which means a number of little wheels have been put in motion to drain the workings. The moor presents a most desolate aspect, being absolutely treeless, and studded with irregular banks of gravel, scarcely covered by a scanty herbage, between which are deep black pools, the relics of abandoned works. About a mile below Porkellis, at Trenear Bridge (where the substructure of a building said to have been a hunting-seat of the old Earls of Cornwall is still seen), the Granite hills on the eastern side close in upon the valley, which for another mile is much contracted. The whole of the alluvium has, however, been streamed probably more than once, but during late years the banks have been carefully levelled and covered with a thin stratum of soil, so as to convert the land into meadows. At Tregrannack the Killas or Clay-Slate formation is entered upon, the surface junction of the tin rocks crossing the valley obliquely. The valley here spreads out into a large basin, which at some remote time has

been very carefully streamed. The alluvium is here mixed up with large boulders of Granite and Greenstone, patches of which occur here in the Clay-Slate, and it is noticeable that the gravel underneath these boulders, where they were too large to be turned over, has been scraped out by using some long-handled instrument. The slopes of the hillsides, formed by the detritus of the Clay-Slate, have been perforated by small adits at the base, in order to extract the subjacent gravel, so that it is difficult to find the smallest portion of alluvial soil left in its original position. Many of the Greenstone and Porphyritic boulders have one or more hemispherical cavities on their surfaces, as if the tinstone was pulverised by hand in these rude mortars. Other fragments of probably a much later date (generally of Granite, which would admit of being more easily shaped for the purpose) evidently formed portions of rude grinding-mills of the fashion of the Chilian "arastras." They were driven by water, and the rubbing surfaces are deeply grooved in concentric rings by the hard material they were used to treat. Just above the surface junction of the Granite and Clay-Slate rocks the valley is crossed by a hard bar of rock, which is now extensively quarried. In opening the quarries a few feet above the level of the river a number of circular cavities were found, ranging from about 5 inches to 18 inches in diameter, and from 4 to 6 or 7 feet deep; the contents consisted of pebbles of almost pure Cassiterite. At the time of their discovery the peculiar formation of these deposits caused much discussion among the miners, more especially as the horizontal fissures, leading into them, were so narrow that they could not be seen till the rock above had been quarried and removed; from which circumstance it was erroneously supposed that the pits were quite imbedded in the solid rock. The real origin of these formations was no doubt due to the eddying of the water about the margin of the stream, which, carrying the hard tinstone round and round, in course of time disintegrated the rock and hollowed it into these peculiar circular forms. To have effected this a very long period must have been necessary, and the quantity of water flowing through the valley must have been much greater than, from its present surroundings, can now appear possible. It may be noticed that, in the Slate cliffs about Newquay, cavities of a similar shape may be seen in course of formation between high and low water mark, one or two fragments of hard stone being seen at the bottom of the hollows. Evidently by their grinding action, when moved about by the eddying water, those wore the softer rock, and gradually deepened the pits in which they lie, and from which it is scarcely possible they can be thrown out by any turmoil of the waves.

It is noticeable in the Cober Valley, above the junction of the rivulet with the Loe Pool, that nearly all the affluents to the main stream come in from the north-west, a circumstance that is perhaps due to a peculiarity in the cleavage planes, or bed-ways of the rock, giving the springs a tendency to issue in a particular direction. On the sides of the valley opposite to these affluents (which are now insignificant) the slopes become very steep, in places almost precipitous, suggesting the idea, that at the time of their formation the springs were much more copious than they now are. At one place, nearly opposite the opening of the branch valley from Trevarno, a

shelf projects horizontally from the opposite side of the valley, the surface of which is covered with a thick stream bed, from which the tin has long since been extracted, leaving the heaps of water-worn pebbles, which are of precisely similar character to those covering the bed rock in the present bottom, 30 feet below.

To a greater or lesser extent the whole of the alluvium, down to the Helston town mills, has been wrought by streamers for tin ore, but from this point to the Loe Pool the "overburden" is so deep as to present considerable difficulties in the way of reaching the bearing ground, though local tradition affirms that it is very rich. One vigorous effort was made about the year 1840, when a large square pit was sunk, the sides being strongly boarded. Much of the overlying matter passed through, in this work, was found to consist of leaves and twigs of hazel and alder, compacted together, and so preserved by the bog-water, that the natural colours of the leaves were apparent as the masses were first turned up by the spades of the workmen. A few days' exposure to the air, however, completely decomposed the mass into a black viscid mud, which pressed so heavily upon the timbered sides of the pit as to crush it hopelessly together. The distorted sides of the excavation, and the reeking mass of black slimy mud, presented so melancholy an appearance, that the name *Wheal Caudle* was instinctively applied to it. The intention was to have driven levels in all directions from the bottom of the open excavation, but it was found impossible to effect this, and although it was understood the produce was not unsatisfactory, the undertaking was abandoned.

While in progress, strict watch was kept for any organic relics in the stream ground, but beyond large trunks of oak and elm trees mixed up with the vegetable matter nothing particularly noteworthy was found. The leaves lay nearly all horizontally, as if they had been brought down by the stream into a still pool, and had there quietly sunk to the bottom.

It may be remarked that, while the Granite formation about the upper part of the valley is traversed by tin-bearing lodes, just below the surface line of junction with the Clay-Slate, where bands of Greenstone crop out, there occur several copper veins, one of which at Wheal Trannack was very successfully wrought on for some years, the workings attaining a depth of above one hundred fathoms. Below the Trevarno Valley the rocks are traversed by lead lodes. One of these, at the very margin of the Loe Pool, was worked extensively about the latter part of the last century—it is reported, to a depth of sixty fathoms—and a large quantity of rich silver-lead ore obtained. This was melted on the spot, where numerous portions of the lode are still thickly strewn about. To prevent the flooding of the workings of this mine by the overflowing of the lake, an adit was tunnelled through the solid rock at the north-west extremity of the bar, or bank of shingle, that separates the Loe Pool from the sea. Owing to the violence of the waves throwing up sand, and choking the outlet, this enterprise did not altogether answer the purpose, and the difficulties connected with the drainage brought about a failure of the mining undertaking.

The Wheal Vor Mine.—A feature likely to arrest the notice of strangers in the mining districts of Cornwall is the numerous small enclosures into

which the land is divided. A plausible reason for this is given by the fact that when mining was not profitable the miners turned to farming; and as the commons were, by spade industry, brought into cultivation, the fields or "quillets" of land were hedged round in dimensions suitable to the small scale in which they carried on their work. There was a fashion prevalent among miners, by which they bequeathed their experience to those that came after them, by planting in the banks adjacent to the places where they had obtained favourable results a sprig of the elder or "scaw" tree, while, the oftener recurring places, where their labours had been fruitless, were marked by the significant emblem of a black thorn. It is an old proverb among miners that a "good lode is good from grass," and experience of the best mines shows that large deposits of mineral generally crop out shallow on the course of the vein. It is just such a history as this that appears to belong to the famous Wheal Vor mine, or, as it should perhaps be more properly spelt, in its old Cornish form, *Huel Veor*, signifying "the Great Working." The vein upon which the chief workings occur bears a few degrees north of east, being just at right angles to the Granite ridge of Tregoning Hill. On the north-west summit of its two-peaked top are the relics of the ancient earthworks from which this hill derives its name, *Tre-Konning*, or the "King's Place." The outcrop of the mineral appears to have been against the "great flookan," which formed the natural western boundary of the late sett, and on the soft back of which the valley was worn out by the spring which, previous to the adits being driven in, was supplied from the porous portions of the vein. Probably this outcrop was turned over to as great a depth as could be reached by the early miners; but the first record of the working of the ground as a mine, relates to its being a portion of the extensive works carried on by the Godolphin family, in the fifteenth and two following centuries. The ore course was then apparently followed down as far as the means of drainage enabled the miners to go; and it is reported that one of the earliest steam-engines was erected here to pump out the water. This was probably towards the close of the seventeenth century. From about 1705 to 1715 it is said that one of Newcomen's engines worked on the shaft, in front of the account-house still standing, by which means that shaft was sunk 60 fathoms under adit. Here the ore course appears to have become small, and operations were abandoned shortly after the latter date. The mine was certainly left in abeyance till the year 1812, when Captain John Gundry,—a member of an enterprising family of miners, resident at Goldsithney,—recommenced operations by employing a Mr. Bratt to put up a steam-engine on the old shaft.

The report of the former productiveness of the mines appears to have been kept up, and on this becoming known, a rumour went through the district "that there would be a plenty of tin to be had, as Wheal Vor was going to be worked again." The surface at this time was described as presenting the appearance of two deep parallel trenches, covered with brambles, evidently the remains of the early open workings. On proceeding to drain the works, a "sollar" or platform was found in the shaft near the adit level which had six holes through it, corresponding to six rods that were reported to have been hung from the beam of the old

Newcomen engine (one to each drawing lift of ten fathoms). The holes probably served as guides to the rods. The bottom of the mine was found to be 60 fathoms below the adit (which is 30 fathoms from surface at this place), and the lode at the deepest point was small and poor. In the course of a few fathoms' sinking, however, a branch of tin ore was discovered in the shaft, which gradually increased in size till the mine became profitable. Unfortunately this was not in time to save the enterprising projectors from bankruptcy, and the mine passed into other hands.

The Wheal Vor lode underlies north about two feet in a fathom, and the shoot of ore from its outcrop in the western part of the sett dips last as it deepens at about an angle of 45°. When a depth of 115 fathoms had been reached, a cross course, subsequently known as Woolf's cross course, was encountered. Here the lode appeared to be completely cut out, and every effort to discover it on the other side for a long time failed of success. One of the miners, called Beaglehole, persisted in the opinion that the "heave" had been to the left or north side, and he was allowed to have a pair of men to drive in the direction he had indicated. In a comparatively short time he succeeded in finding one of the richest and most continuous courses of ore ever found in any country. The general dip of this ore ground continued as before, an average angle of 45°. It was not always of the same richness, but at times, when the value diminished, the richer portion would again be found, on driving farther east, the whole roughly resembling a succession of large irregular steps. About 150 fathoms to the east of Woolf's cross course a second cross course, to which the name "Bounder" was given, was met with, and here again the ore deposit greatly increased in size and richness, and so continued to within a short distance of the present bottom of the mine at 310 fathoms below adit, showing every sign of maintaining its productiveness as it approaches a third cross course known to exist about 100 fathoms still farther to the east.

It was noticed that where the lode was most productive, the cleavage joints dipped into it nearly vertically on the north, or hanging wall. These joints were filled with veins or strings of tin ore, accompanied with white lithomarge or "*prian*." These strings were so numerous and rich, that the rock containing them was often excavated to a width of above 50 feet, and in some instances to more than double that extent.

To treat the immense mass of ore stuff raised from these great excavations, it became necessary to extend the operations of preparing the ore for market to a vastly greater scale than had previously been required in Cornwall. At first the water power available in the vicinity of the mines was employed to work stamping-mills, for pulverising the mineral, and as much of this was exceedingly hard, kilns were put up, in which it was calcined before being subjected to the stamps, in order to facilitate its reduction, an expedient that perhaps might at this time be adopted in other tin mines with advantage. Eventually steam was, for the first time, applied to provide stamping power, thus saving the heavy cost and loss attending the carriage to the water stamps; to this was added furnaces and appliances for smelting the ores, which, amounting at one time to nearly one-third of the total produce of Cornwall, there was some difficulty in

disposing of at a satisfactory price, in the form of ore or black tin. Indeed, the adoption of this course seems to have been a necessity, for early in the year 1826 we find the purser applying to a business friend in London for advice on the subject, to which the reply was clear and decisive, "The adventurers must go on smelting or stop the mine." The price for metal at this time was £88 per ton. To the original Wheal Vor mine the adjacent setts of Polladras Downs, Penhale, and Carleen were subsequently added, and the gross produce of the amalgamated mines, at one time, reached 220 tons of black tin in a single month. Seeing the great apparent influence of the cross courses in enhancing the productiveness of the lode in Wheal Vor, an idea prevailed among the mine agents, that as the shoot of tin in Carleen mine—at the extreme west against the Granite, as it dipped east—came in contact with the great cross course, forming the boundary between that sett and Wheal Vor, similarly good results would be found near this junction. It was hoped that this would be the top of a second course of tin ore which would underlie all the workings that were then so productive, and it was their hope that at some time the extension in depth of the old western shafts in Wheal Vor would enable them to prosecute their explorations in this direction.

This hope, however, was not realised, for in consequence of circumstances arising from the bankruptcy of the Messrs. Gundry—the original projectors of the mine—legal proceedings were entered upon by their representatives to recover possession of the property. The litigation in the Court of Chancery lasted for about twenty years, hampering the operations and ultimately bringing this magnificent enterprise to an untimely end in about 1848. The surface refuse of the mine continued, however, to be worked over till about the year 1852, when a new company was formed to reopen and extend the operations of the old mine. In the *Mining Record Office*, plans and sections of the Great Wheal Vor, completed up to the closing of it in 1848, were preserved, showing that the bottoms of the mine were exceedingly poor when they were abandoned. Had these drawings been carefully examined, and the indications, shown by the constant lessening of the "*stopes*," been attended to, it is not probable that any set of mine adventurers would have been persuaded to incur the enormous cost of pumping out the water from the vast extent of subterranean workings. This was effected by the erection of a magnificent pumping-engine, having a cylinder of one hundred inches diameter, which was considered by all, as one of the finest works of Mr. Michael Loam, the well-known Cornish engineer. The history of this undertaking would show one continued series of unfortunate blunders and mistakes, so that the water was scarcely got out of the workings before the company was involved in difficulties. The mine was again allowed to be filled with water, and the remaining resources of the company were applied to the development of a parallel lode to the south. The result was very successful, a profit being realised of about £100,000. A total depth was reached of 220 fathoms from surface, and the works were continued till their abandonment during the depression of 1877.

In the moors of Towednack, Wendron, St. Austell, Luxullion, Alternun, and a few other places, the tin ground lies far within the boundary of its

native rocks, the earthy ingredients of the rock so closely resembling the general character of the minerals as to prevent absolute identification of the rocks and veins. The *detritus* which has been reft from these, and which forms the *tin ground*, occurs near the junctions of the different systems, as in the swamps of St. Austell, Luxullion, and St. Columb Major. The débris of the geological stratum immediately beneath generally prevails, sometimes, indeed, to almost an entire exclusion of the associated ore. Generally speaking, however, the fragments are intimately mixed, but frequently not in the same proportions throughout. This, however, is not always the case, for at Carnon stream the upper and the lower parts vary in their mineral character, the lowest being the richest in tin.

Carclaze tin mine has been one of the best examples of this class of formation, as well as of a mine "worked open to day." The excavation at Carclaze, when Mr. Thomas wrote a description of it half a century since, occupied five statute acres, its depth was 136 feet, the solid contents 63,000 cubic fathoms, and tin to the value of a million sterling had been removed. M. Jars * thus describes the works as observed by him more than a century since: "About two miles from the town of St. Austell is a mountain slightly elevated, but very extended, which forms a *filòn en masse*, which we call in Germany a *stockwerk*. It is a rock of the nature of Granite, of a white colour, and very friable, which contains an infinite number of small veins of tin. These veins are almost always parallel, and their direction is east and west. The part of the rock which is not worked is of the same nature as the worked portion, but very much harder. It is broken out, however, with a pick and wedges of iron."

MM. Von Ocynhausen and Von Decken† give the following account of this remarkable open-work:—

"The mine forms a large excavation open to day, and is said to be 250 fathoms in length and 100 fathoms in breadth, and 21 or 22 fathoms in depth. The direction of the greatest length of this remarkable opening is 30° north of west. In the eastern part of the excavation are several shafts sunk below the bottom of it, by which tin ore is raised to a depth of 10 fathoms under the adit. The Granite of Carclaze is intersected by numerous veins and strings of tin ore, and adjoining those veins the Granite also contains tin ore. These veins consist chiefly of quartz and schorl. . . . . These tin lodes run in every direction through the Granite, but they are more prevalent in one direction than in any other, that is a direction 22° north-west; their underlie is towards south; the angle they form with the horizon is 35°. The distance between these veins is very short, so that they give to the rock a stratified appearance. Other tin lodes run between 15° and 30° east of north. They intersect the former tin lodes without heaving them, and also without being heaved by them. It is said that very rich tin ores are found where these different lodes intersect each other."

Prof. Sedgwick‡ thus describes this interesting geological phenomenon:—

* M. Jars, "Voyages Métallurgiques ; ou, Recherches et Observations sur les Mines et Forges de Fer, &c., faites depuis l'année 1757, jusques et compris 1769, en Allemagne. Suède. Norwège. Angleterre. Écosse, &c." 3 vols. 4to. Lyon: 1774.

† "Philosophical Magazine and Annals" in 1829.

‡ "Cambridge Philosophical Transactions," vol. i. p. 108.

"The enormous open work of Carclaze, near St. Austell, is an object of no ordinary interest. The traveller may there see the operations of the miner carried on in the light of day, without being compelled to descend a hundred fathoms below the surface of the Earth, and then to crawl into a dirty dripping cavern. The works are excavated in a variety of decomposing Stanniferous Granite and schorl rock, The chief constituents are quartz, felspar, schorl, and oxide of tin, with occasional specs of mica. Throughout the whole extent of the excavation we may trace a succession of parallel veins of schorl rock, which do not in any degree partake of the decomposition of the metalliferous beds, and appear both in their range and dip to cor-

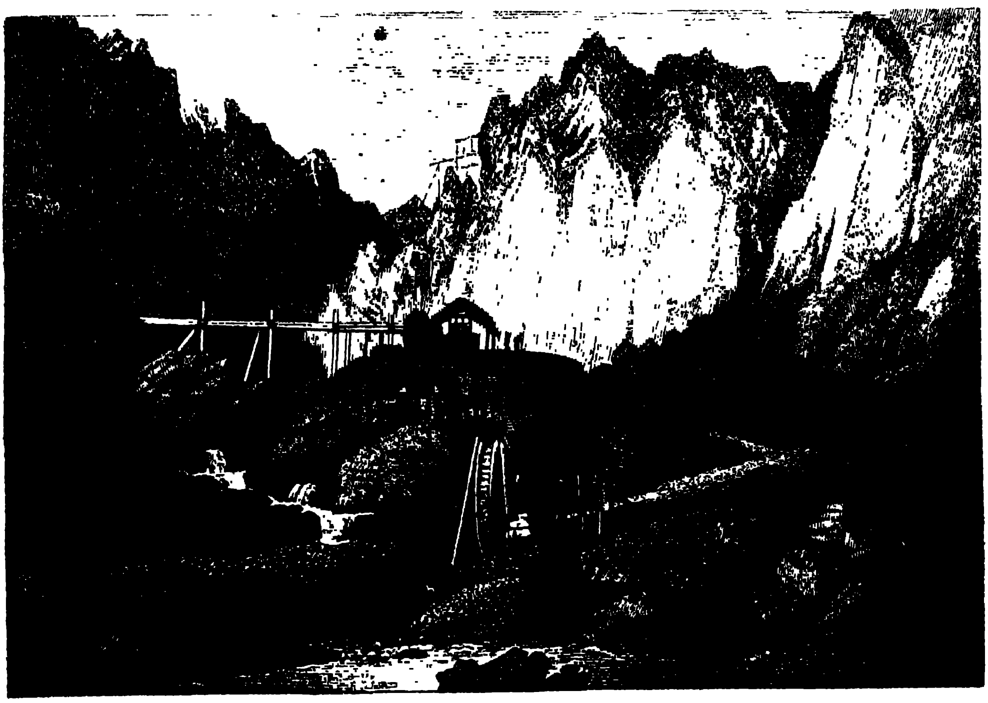


Fig. 69.—Carclaze Tin Mine.

respond exactly with the beds of *Killas* in the immediate neighbourhood." (See Figs. 69 and 70, the first representing this remarkable excavation in perspective, the other in plan, drawn carefully to scale.)

Professor Sedgwick appears to be greatly in favour of the view that most of the veins in Cornwall are veins of segregation. He says, especially referring to this excavation:—

"In all the crystalline Granitoid rocks of Cornwall there are also many masses and *veins of segregation*. Such are the great contemporaneous masses and veins of schorl rock, and some of these are metalliferous. The decomposing Granite of St. Austell Moor is traversed and sometimes entirely superseded by innumerable veins of this description. Upon these lines of schorl rock there is often aggregated a certain quantity of oxide of tin, which sometimes *diffuses itself laterally into the substance of the contiguous Granite*." The con-

cluding passage of this quotation is very obscure. That a mind of the power of Sedgwick's, which in a remarkable manner appeared always equal to the penetration of the obscurity of an hypothesis, should yield itself to the idea that *any* separate action of secondary diffusion took place in the masses such as he is clearly describing, is not easily understood.

Dr. Boase, an equally cautious observer,* remarks: "The upper part is much decomposed, but beneath it gradually becomes more solid and perfect. It is traversed with innumerable *strings* and *bunches* of schorl and schorl rock, which abound in tin ore. These *irregular veins are evidently contemporaneous with the Granite*, for they are so intimately blended together that in order to obtain the ore both veins and rock require to be stamped and washed."

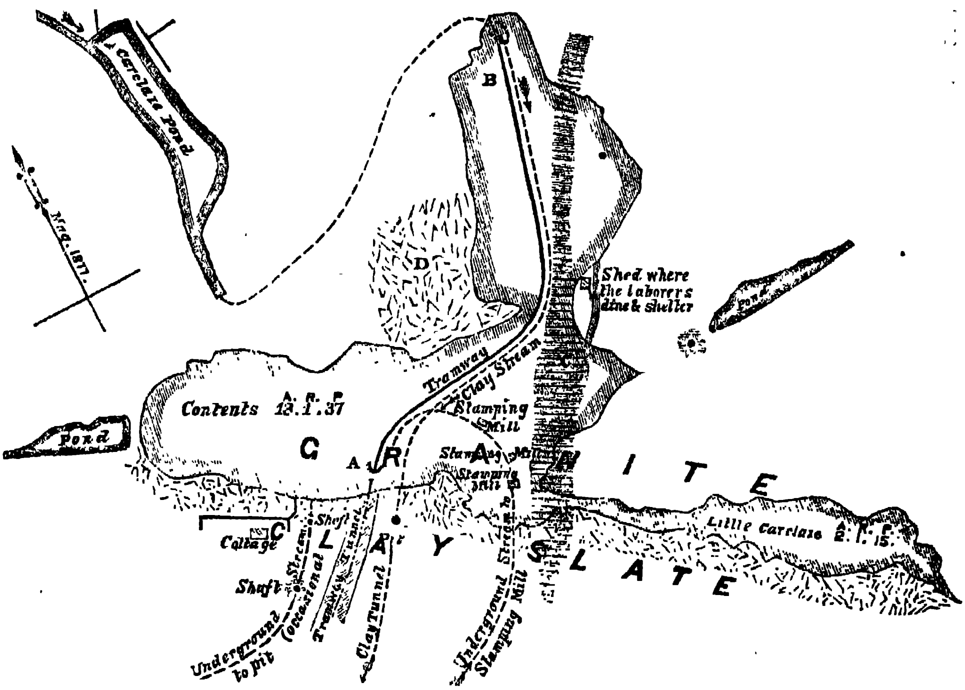


Fig. 70.—Plan of Carclaze.

Mr. Hawkins remarks †: "Like all veins which traverse those hills they (the *lodes* of which were at one time quarried) are composed of quartz and schorl, and carry more or less tin, which are so united with soft and hard growan that no doubt *can be entertained of their contemporaneous origin.*"

If we enter Carclaze mine from the south the Granite and the Slate pass almost imperceptibly into each other through a medium of compact rock mostly composed of schorl and felspar which are often mixed, and occasionally in alternating laminæs. In some places, however, this rock is quartzose, whilst in others the quartz assumes a veined structure.

When mining operations were actively carried on here, a stamping-mill, worked by steam, was erected at the very bottom of the excavation. The old

* "Royal Cornwall Geological Transactions," vol. iv. p. 238.
† Ibid.

steam-engine still remains, but it has long been out of use. Now several water-wheels propel the machinery for crushing the tin stones. Within memory the adit level was navigable, and the tin was removed in a boat.

The Granite of Cligger Head, which is in many respects remarkable, possesses much in common with the Granite of Carclaze mine. It is traversed by narrow veins of quartz, and both the rock and the veins contain tin ore. The action of the sea saps the base of the cliff, and large portions of it fall every winter.

Dr. Clement Le Neve Foster* has well described analogous formations at Wheal Prosper and Michell, and also at Mulberry, a few miles from Bodmin. He states that the Granite is traversed by numerous branches or veins running north 7° west, dipping about from 80° to 90° west, and varying from mere joints to veins 4 or 5 inches in width, rarely more than a foot apart, in fact generally only a few inches. Many of the veins preserve their independence for a considerable distance without intersecting other branches; but at the same time it is easy to find junctions both in the dip and in strike; sometimes also two adjacent strings may be connected by a "floor" or bed of tin following the stratification. In addition to oxide of tin the beds contain quartz and a little arsenical pyrites and wolfram. The appearance of the north end of the quarry will be readily understood by reference to Fig. 71, which shows the general mode of working.

Men, standing at A, bored holes and blasted them, which threw the rock to B, under which a level has been driven with an opening C, usually closed by a hatch. A waggon is run in, and by opening the hatch it is filled without labour. As the face of the quarry gets farther and farther north from the removal of a succession of more or less vertical slices, the level is driven on ahead and another hatch made.

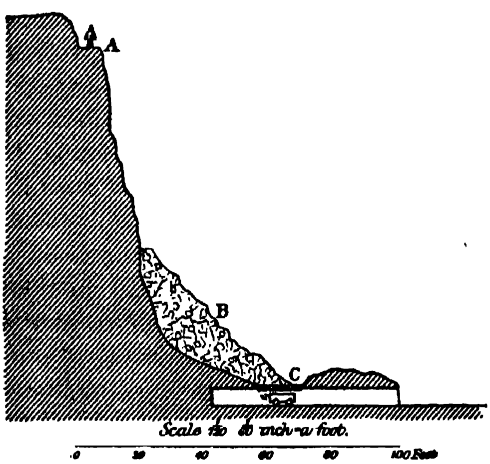


Fig. 71.—Section of Mulberry Mine.

The stuff is trammed to a distance of about a quarter of a mile to stamps worked by water power; and even at present prices this poor tin-bearing rock, containing not more than 7 lbs. of tin to the ton of stuff, or about one-third per cent., is made to pay all expenses.

Dr. C. Le Neve Foster also well describes a mass of *Greisen* (altered Granite) at Hensbarrow, which cannot fail to be of interest.

"*Carrigan*, about two miles east north-east of Roche, on the northern edge of the great Hensbarrow boss of Granite, affords the finest display of *Greisen* in the county of Cornwall. The mass of *Greisen* wrought at Carrigan quarry is known for a width of 50 yards and a length of 100 yards and a depth of 60 feet. On the south-east side it is bounded by a large clay vein or *flucan*, and on the north it disappears under the alluvium of the neighbouring valley.

* "Quarterly Journal of the Geological Society" for August, 1878.

The rock is a mixture of quartz and mica with a good deal of schorl, some Gilbertite, and a little iron pyrites, fluor, and Cassiterite. The mass is traversed by a number of so-called *leaders*, which are quartz veins with tin ore, schorl, Gilbertite, and clay, dipping 85° south, and running east 7° north. Very often they are 1 inch or 2 inches wide, and from 1 foot to 6 feet apart. Occasionally the *leader* adheres to the enclosing rock (*country*) by one side only, and has a clay vein on the other. On washing the clay, broken crystals of Cassiterite are generally found, proving that since the deposition of the tin ore, in the fissures, there has been a movement of the walls. When tin was at a higher price, this mass of *greisen* and tin veins was quarried and stamped on a large scale; in fact, 27,500 tons of rock were stamped, yielding 64 tons of tin ore, or 5·2 lbs. of tin (*black tin*) per ton, say ¼ per cent. It was expected that the wholly virgin ground would produce 8 lbs. of tin ore per ton. As the rock is very much harder than the Killas of Mulberry, it cannot be profitably worked at present prices."

West Rosewarne and other Mines.—The mine first named does not exhibit any mining operation of a novel character, nor is it remarkable, beyond other mines, for peculiarities in the lodes. There are, however, some phenomena deserving attention both in West Rosewarne and the neighbouring mines. These are, the presence in the lodes of matter which has been derived from extraneous sources, which serve to advance our knowledge of the age of veins. At the 74-fathom level in the West Rosewarne mine some large Granite boulders were met with, some years since, sometimes in the lode, and occasionally both in the lode and the country. The lode at this mine is almost entirely made up of *breccia* (principally angular fragments of Killas); and the "country" in which the boulders occur is also itself of a brecciated and conglomeratic character, and this to a curious extent. These boulders and pebbles range from ½ an inch up to 12 inches in diameter, and are called by the miners "bullies," the small ones being called "young bullies" and the larger ones "grown bullies." As a general rule, these rounded pebbles and boulders seem to be found in the "country" and in the neighbourhood of the lode, but *not* usually in the *lode* itself, nor in the country at any distance from the lode. These conditions exist over the whole of the surrounding country, conveying to the mind the idea of its having been subjected to some violent disturbance. The area which presents this confused condition is limited in extent, and therefore the conclusion is forced on the mind of the observer that some peculiar force, probably due to pent-up vapour or steam, has been suddenly liberated, which thus rended and lifted the rocks forming the country.

Of *Relistian* mine, Mr. J. Carne says: "Here, at a depth of 100 fathoms below the surface (which is not higher than the surrounding country), a mass of pebbles was discovered *in* the tin lode. The pebbles are of Slate, the same as that of the country. In the crevices between the pebbles, and connected with the cementing substance, are oxide of tin and yellow sulphide of copper, the former always crystallised, the latter never. Mr. W. J. Henwood confirms this: "At Relistian the Slate contains numerous spheroidal concretions, some of them are compact, others schistose Slate, and others entirely of quartz."

In *Herland* mine, about 110 fathoms deep, there were numerous nodular masses of Granite, which consist of a base of felspar with some quartz and a little mica. They were fine and decomposing, varying in size, and whilst some are not larger than a hazel-nut, others are two or three feet in diameter (*Henwood*).

Mr. H. C. Salmon, who appears to have examined these boulders with much care, comes to the conclusion that "the whole bearing of the evidence shows that the boulders must be taken as having been subsequently introduced, and most probably through fissures from the surface. Mr. Salmon concludes his notice of these phenomena in the following words: "In searching for an elucidation of the obscure and complicated causes under which metalliferous lodes have originated, nothing is more important than to endeavour to ascertain what periods of time have elapsed between their formation and that of the eruptive rocks with which they are generally associated." *

In the formation of fissures, it is evident that the active force by which they have been produced must have propagated a wave, by which the elevation and depression of the surface of the country to an unknown depth was effected. Of this, the veins are a sufficient evidence. In producing the larger rents, splintering of the rocks must have taken place, and the fragments broken off must have fallen into the veins. Beyond this, during the period in which the deposition of the ores, from whatever cause, was taking place, there must have been constantly fragments splitting off from the sides of the cracks, and these are no doubt the angular fragments which we find imbedded in the matter of the lode or enveloped in the metalliferous ore.

During one geological period—probably the Glacial epoch—by the breaking up of the Chalk formations, flints were scattered over all Western Devon and Cornwall, and they are found even at the Scilly Islands.

The late Mr. Samuel Higgs, jun., found a chalk flint at the bottom of a "*vug*," or cavity, of the so-called New lode, at the 130-fathom level, in Balleswidden mine, surrounded with decomposed felspar and quartz. The vug was about 18 inches square, and the lode in this place 7 feet wide. Similar flints are distributed over the surface on Solger's Croft, near Carn Kenidjack.†

Water-worn stones have also been found in South Wheal Frances. They were discovered a little above the 82-fathom level—about 105 fathoms from the surface—near the middle of the vein, which at this point was chiefly composed of rich copper ore.‡

Organic Remains in Mineral Veins.—Mr. Charles Moore § published a memoir on mineral veins and their contents, which will form an instructive addition to the descriptions already given.

The views entertained by this observer are beyond our purpose. His investigations into the evidence afforded by fossils of the ages of veins is the

* Consult a paper by Joseph Le Conte in the "American Journal of Science" for July, 1883. Mr. Le Conte's hypothesis supposes the water, percolating the rocks, penetrates to great depths, acquires a high temperature, and, dissolving earthy and mineral matters, exhibits solfataric action, and fills the fissure through which it is forced with the earthy and metalliferous matters forming veins.

† "Transactions of the Geological Society of Cornwall," vol. vii. 1865.

‡ John Rule, "Transactions of the Geological Society of Cornwall," 1865.

§ "Report on Mineral Veins in Carboniferous Limestone and their Organic Contents." By Charles Moore, F.G.S. ("Report of the British Association for the Advancement of Science" for 1869.)

only portion of his report with which it is intended to deal. Mr. C. Moore introduces his subject by stating that Sir Charles Lyell mentions* that M. Virlet had found a *gryphæa* in a lead mine near Semur in France, and that a madrepore had been seen in a compact vein of cinnabar in Hungary. He then continues :—

"One reason for the non-discovery of organic remains has arisen from their being generally of small size, and that the vein-stuff in which they have to be sought for is often of a very intractable character, resisting the action of the water, by which it has to be dissolved, before they can be washed out of it, after which the residuum requires almost microscopic examination for their separation. The organic remains thus obtained are occasionally even more varied, as regards genera and species, than if they had been derived from a given horizon of stratified deposits, arising perhaps from the length of time within which the fissure might have been open and the necessarily mixed condition, consequent upon the filling of the vein. Some from the Carboniferous Limestone itself are associated with those which are foreign or derived. In the case of the *Charterhouse* mine on the Mendips, those which are of Liassic age, and consequently derived from that rock, are in the proportion of about 90 to 30 from the older rocks within the walls of which they are found. In the Carboniferous Limestone districts of Holwell and Frome, Rhœtic and Liassic organisms are also in large proportion; and the same may generally be said, throughout the Mendip range and South Wales. In North Wales and the North of England, on the contrary, Carboniferous Limestones are the most frequent; those of later age are the exceptions, some of these being *Entomostraca* of Permian species and *Foraminifera*, which have a long range upwards."

Charterhouse mine shows that a considerable time must have elapsed within which the lodes remained more or less open, and during which various oceanic influences were at work. At 270 feet—the lowest depth of the Charterhouse shaft—there is found a deposit of blue clay 10 feet in thickness which yielded a considerable number of Lias fossils (Mr. Moore enumerates 75). This, on the same level, changes from a homogeneous marl to patches of a more conglomerated material with enclosed water-worn pebbles. Higher up the vein it becomes a dense conglomerate. Above this sandy deposits occur, which, when washed, are seen to be almost entirely composed of the detached stems of *encrinites* very much abraded, with small washed pebbles of hæmatite iron ore, "showing that, after the deposit of the Lias in the vein below, a denudation of the Carboniferous Limestone had been going on, and above this again occurred calc-spar and the largest deposit of lead ore." In addition to the 75 Lias fossils, a list of 28 are given by Mr. Moore as belonging to the Carboniferous Limestone.

"In other mining districts organic remains are generally less plentiful than in the Mendip area, but I have not failed to detect them, more or less abundantly, except in one instance—in that of the Cononly mine, in the Airdale district." The following list has been abstracted from Mr. Moore's report :—

Keld Head Mines, Wensleydale.—Organisms rare at 48 feet, but *Encrinites, Involutoria*, and *serpula-like tubes* detected. At 90 feet *Encrinites*

* "Elements of Geology," p. 762.

very abundant with galena and iron pyrites. At 192 feet *Encrinites* abundant. At 210 feet *Valvata Anomala*, *Entomostraca*, *Echini*, and *Encrinites*. At 240 feet, West Bank vein, *Foraminifera*, *Encrinites*, and *Serpula*, *Bryozoa*, &c. At 450 feet, with galena, blende, iron pyrites, &c., *Euomphalus*, *Entomostraca*, *Encrinites*, *Echini*, *Serpula*, *Terebratula*, &c., abundant. A list of 57 fossils found in Keld Head mines is given.

Fallowfield and Brownley Hill Veins.—The latter at 1,400 feet and the former 100 feet above sea-level, and at depths from 90 feet from surface to 600 feet, a list of 23 fossils is given.

Grassington Mine.—From the 24-fathom level to the 45-fathoms, at the height of 1,300 feet above sea-level, a list of 51 organic remains is given.

Alston Mines (1,240 feet above the sea-level).—Twenty-nine fossil remains have been collected from the vein.

Weardale Mines.—Twenty-two varieties of organic remains have been collected.

The Allenhead Mines have yielded 32 specimens of different organic remains from its various lead lodes at several depths.

The White and Silver Band Mines give, from the lead lodes, a list of 19 organic remains.

Coldberry and Redgroves, in *Teesdale*, yield 20 varieties.

Mount Pleasant Mine, near Mold, in Flintshire, yielded 24 fossil varieties to a careful search.

Mr. Moore concludes his interesting paper in the following words :—

"Not the least important fact in my mine explorations has been the discovery of a land and freshwater fauna. Until I obtained the three genera of *Helix*, *Vertigo*, and *Proserpina*, with the freshwater genera *Planorbis* and *Valvata* in the Charterhouse mine, the only known terrestrial shell was the *Papa-Vetusta*. To the above genera I have now to add those of *Hydrobia*, *Stoastoma*, *Lithoglyphus*, and *Pisidium* from the mines of the North of England. There is thus the fact of the presence of nine genera of land and freshwater shells in the lead veins of this country."

In addition to the list of organic remains [given as an appendix to Mr. Moore's report], numbering about 112 species from the North of England and North Wales mines, "eight, which are not common, have been obtained from Weston, and to these again are to be added 89 from Charterhouse, so that in true and workable mineral veins I have found 209 species. I have discovered the oldest known Mammalia, the oldest land and freshwater Mollusca, about 52 species of fish, and about 8 of Reptilia."

Clifford Amalgamated Mines and others in Gwennap.—The Wheal Clifford, from which the present name was adopted, was included with the Consolidated and United mines in 1819. These mines are situated about a mile south-east of the village of St. Day, about seven miles from the shipping port of Portreath, and about four miles from Restronguet Creek, which opens into Falmouth Harbour. The Consolidated mines, as they were formerly called, included within their sett (as the ground included within the boundary of a mine is provincially termed) Cusvea, Wheal Fortune, Wheal Lovelace, East Wheal Virgin, and West Wheal Virgin. These were all worked as separate mines until towards the end of 1818, when the union was first contemplated; but

the arrangement was not completed until the following year. The "sett" of the Consolidated mines extended from near the mouth of the great Gwennap adit eastward, to within a short distance of the village of Carharrack westward, being about 1,500 fathoms, or a mile and three-quarters, in length, and averaging about 300 fathoms in breadth. To this sett the United mines was joined in 1824, which included Ale and Cakes mine and Poldory, and still more recently Wheal Squire has been added. The United mines sett adjoins the Consolidated sett to the south for nearly two-thirds of its length. To the east the boundary is formed by an imaginary line crossing the country to the west by the "great cross course,"* and to the south partly by a stream running nearly parallel to that which bounds the Consolidated mines to the north. The area included in these combined mines is about 1,200 acres, or nearly two square miles. Some idea may be formed of the mineral wealth of this tract, by stating that within the last eighty years it has given metallic wealth to the amount of £6,000,000 sterling.

The ores are generally accompanied by iron and arsenical pyrites, and occasionally by zinc-blende, and other minerals. The veinstone is almost entirely quartz intermixed, with the copper ore *Gossan* (oxide of iron), which occurs generally on the backs of lodes.

The singular cavities called in Cornwall *Voughs* (pronounced *Vughs*† or *Vugs*) are seen in many of the lodes. They vary in size from two or three inches to as many feet. Their interiors are usually lined with crystallised quartz and pyrites, but they occasionally contain rare mineralogical specimens.

The lodes which are productive, or rather the portions of them which are so, are frequently of great length, often from 206 to 300 fathoms long. The "courses of ore" often extend from 30 to 80 fathoms and more in length. It is commonly believed that wherever a lode is rich, if there be another lode near it having nearly the same direction and in the same *country*, whether in *Killas* or *growan* (disintegrated Granite), or even in an *Elvan course*, it is probable that the second lode will be found rich in that part which is opposite to the rich part of the first lode. "This is not a new doctrine. The phrase *ore against ore* is probably of earlier date than the present generation of miners" (*Carne*). "The occurrence of the richer portions of parallel lodes on the same meridian has been long known and acted on, and indeed seems to have been first recognised in this district" (*Henwood*).

One of the most remarkable works in connection with those mines is the *great adit* which empties itself into Carnon Valley a little above the high-water mark. This was commenced in 1748 by Mr. Williams, who was then manager of Poldice mine. It was begun near Bissoe Bridge, and was extended to the western boundary of Poldice in less than twenty years, and the expense of this portion of it was defrayed by the adventurers in that mine. It was subsequently driven to other mines, all of which it unwatered.

* The *great cross course*, which traverses the mineral district of Redruth, extends quite across the country, being seen in the cliffs of the English Channel and in those of the Bristol Channel. Its direction is nearly that of the magnetic meridian, and the distance it may be traced is about twelve miles. It is chiefly composed of quartz and clay, but in some places it extends to the width of thirty feet, and is filled in with disintegrated Granite, derived, no doubt, from the neighbouring hills.

† "*Fogans*," applied to caverns in the cliffs in West Cornwall, and "gogofau," or "ogofau," as applied to the Roman gold mines in Carmarthenshire, are evidently forms of the same term.

The length of the adit with the various branches amounts to about 26,000 fathoms, nearly 30 miles, and the greatest length to which any branch has been extended from the adit mouth is at Cardrew mine, which is about 4,800 fathoms, nearly 5½ miles. The highest ground it has penetrated is at Wheal Hope, where the adit is 70 fathoms deep at Chilcot's shaft, and is deeper in the branches extending from thence.

The general character of the rocks of this district has been already described. Some of the masses of Elvan, however, require additional notice. The principal body of Elvan known in the Consolidated sett traverses Coisgarne Downs in an easterly and westerly line. This is a large irregular mass of great width and extent, penetrating the Killas in various directions. Elvan is also known in several other parts of the United mines and in Wheal Squire. These Elvans vary in texture and appearance. Their colour is usually a light brown, but often they are greenish or greyish, and in texture and composition not very unlike Granite.

The mineral veins or lodes worked in these mines are large and regular and very numerous. There are about eight or ten which may be called principal lodes, besides a great number of smaller lodes or "branches" either running parallel to or crossing the former. The direction of the principal lodes is either very nearly east and west, or a few degrees north of east and south of west. That of the smaller ones or contre (*caunter*) lodes is nearly north-east and south-west. The width of the principal lodes in the Consolidated mines averages about 3 feet, but occasionally they reach 4 or 5 and even 8 or 10 feet. In the United mines 4 or 5 feet is the usual width of the main lodes, the branches in both mines rarely exceeding from 12 to 18 inches.

The underlie of the principal lodes is towards the north; but the underlie of the smaller lodes is generally south, thus occasioning them to intersect the former in depth. The chief and most valuable produce of these lodes is copper pyrites, or "yellow ore." Native copper, peacock copper, purple copper, grey copper, the blue and green carbonate of copper, and the red oxide of copper, are also found in these mines. All these varieties may be regarded as changes effected by slow chemical action upon the original sulphide of copper, and of iron pyrites. In the United mines native copper has been raised in greater abundance than is usually the case with this metal.

It is necessary that some attention should now be devoted to a consideration of the most remarkable Consolidation of mines which ever existed. Three lodes run through the entire length of the mines in Gwennap, intersected by eighteen smaller ones in different parts. The principal lodes run about 10° north of west and south of east. The others vary considerably, but generally their direction is more to the north of west and south of east.

The larger lodes vary from a width of 10 feet to a few inches, the others from a few inches to 3 feet. They underlie north, with the exception of seven of the smaller lodes, which underlie south.

In July, 1845, there were 23 shafts in use, and a great number of others out of use. At that date 625 miners were employed underground, and 146 boys; which at the surface, men and women, boys and girls,

amounted to 904. In 1815 2,982 tons of copper ore were raised, giving 8⅝ produce for copper. In 1818 11,476 tons of copper ore of 8¼ produce. The greatest quantity of ore raised in any year was in 1845—14,374 tons, with a produce of 7.

In 1824 the United mines were abandoned. The drainage, which had been effected by four steam-engines, was then suspended, and the water allowed to rise in the mines. The bottom workings of that part of the mine called Ale and Cakes were about 210 fathoms below the surface. Eventually it was determined to pump the water from the United mines, and to work them again on an extensive scale.

In 1862 the United mines were incorporated with the Consolidated mines.

The following is a succinct statement of the condition of the United mines at this time:—

Ale and Cakes is the deepest part of these workings, and has been extensively worked both on the main and the branch lodes for about 400 fathoms in length. The adit is cut at about 40 fathoms in depth from the surface, and workings extended 170 fathoms below it, or 210 fathoms from the surface.

This mine occupies an elevated situation, being on the gradual declivity of a range of hills on which the Consolidated mines are situated, and near their opposite escarpment, which declines here both to the south and to the west.

Phillips* informs us that in some of the deepest workings pieces of copper pyrites of a mammillated structure were found loose in the vein. These masses were from 2 to 3 inches long, and exhibited the appearance of having been rounded by attrition.

Poldory adjoins Ale and Cakes to the westward, and has been extensively worked, both on the main lode and on the smaller ones, for near 300 fathoms in length, and in parts to 110 fathoms under the adit. A small building on this mine is said to have been the engine-house of one of the first steam-engines erected in Cornwall. This building is about 15 feet square, so the engine must have been a very small one.

East Ale and Cakes has been worked to about 80 fathoms below the surface, almost entirely on the old lode to which the adit of the United mines is extended.

Wheal Squire adjoins Poldory to the west, the two being separated by the great *cross course*, which is here from 18 to 20 feet wide, and heaves the lodes for a distance of 20 fathoms. This mine was at one time very productive, but after being idle for some time it was added to the United mines.

"The most remarkable feature in Wheal Squire is the numerous dislocations of the lodes of *cross courses*, of which no less than eight were known, several of them being branches of the *great cross course*. In some cases the heaves do not exceed 3 or 4 fathoms, they are frequently as much as 18 or 20. It is worthy of notice, and one strongly exemplifying the action of denuding causes, that the surface of this mine is nearly a perfect level, and presents not a single trace of the tremendous subterranean convulsions which have at different periods affected it to an extent of which there are but few parallels in so limited a space of ground" (*Burr*).

* William Phillips's "Introduction to Mineralogy."

The union of mines known as the *Gwennap Consolidated* mines commenced working under *that title* in 1819, but the *Mining Record Office* has returns from 1815. Those were as follows:—

	Ore.	Value. £	s.	d.	Produce.
1815	322	2,082	11	6	$7\frac{3}{4}$
1816	722	4,025	13	6	
1817	443	2,326	7	6	
1818	429	2,974	17	6	
1819	774	7,258	9	6	

The union of the mines now took place, and we find an increase commences in 1822, which steadily advances:—

	Ore.	Value. £	s.	d.	Produce.
1822	12,861	80,311	1	6	$8\frac{5}{8}$
1827	13,252	92,107	11	6	$9\frac{3}{8}$
1832	15,523	108,886	6	6	$9\frac{3}{4}$
1837	19,210	133,024	8	6	8
1842	11,617	73,558	6	0	

In the Appendix to this volume will be found a general set of tables giving much information as to the cost of mines from the earliest obtainable accounts, and some interesting particulars of the cost of working large and important mines, furnished by the proprietors.

A section drawn across the parish of Gwennap presents the remarkable series of lodes and Elvan courses named in the following list:—

WHEAL UNITY	North Lode South Lode	Elvan course.
POLDICE	James's Tin Lode Singer's Copper Lode Tin Lode Field's Lode Little Lode Tremayne's Lode	
WHEAL MAIDEN	Martin's Lode North Lode	
CONSOLIDATED MINES	Mammell's Branch Bray's Branch Wheal Fortune Lode Taylor's Lode Deeble's Lode Kitto's Branch	Elvan course.
UNITED MINES	Hot Lode Old Lode Middle Lode South Lode California Lode	Elvan course and branches.
SOUTH CLIFFORD		
WHEAL ST. AUBYN		

Although the whole of the parish of Gwennap is metalliferous, Job's district, as it has been called, has proved the most productive. Before the consolidation of the mines, this section was worked as East Wheal Virgin. The deepest points of these workings were near Job's engine-shaft, which is situated about midway between Davey's and Terrill's, and extended to 150 fathoms below the surface, or 110 fathoms under the adit. In the workings at this time a 90-inch cylinder was placed on Job's shaft, and pumps were fixed also in Terrill's shaft, and the two sumps were carried down from their former depth of 90 fathoms under adit to the depth of 135 fathoms.

The levels in this district were extended considerably from the 100-fathom or former deep level to the 210-fathom level, and the Consolidated mines were commonly spoken of as "a new mine under the old one."

Between the 110 and 120 fathom level, a little to the west of Taylor's shaft, a very extensive *vough*, or cavern, was discovered, the size being much greater than is commonly observed, being nearly 40 fathoms in length and from 1 to 2 fathoms high; the direction was nearly horizontal, the lode both above and below producing good ore.

The necessity of an additional shaft in this district for drawing ore and stuff being sensibly felt, it was resolved to sink one from the surface with all possible expedition. The new shaft was to be called Francis's shaft, Captain William Francis being then the principal agent of the mine. For the dispatch with which this shaft was executed and the precision of the work, which was unrivalled, this work was in its time remarkable. The work was begun in March, 1839. The situation chosen was north of the other shafts and on the line of the old lode, which it was to intersect in depth, the underlie being 18 inches per fathom. *Cross cuts* were driven from the adit—the 40, 70, 100, 120, and 135 fathom levels—and while the upper portion of the shaft was sinking below the surface the operations of sinking and rising were carried on from each of the cross cuts mentioned, and also from the 150 and 160 fathom levels, which were already in the proper line, the ground thus being opened in fifteen different places at once. The total depth of the shaft was about 205 fathoms, and on the 31st December the last bar of ground which intervened between the surface and the bottom was *holed*. Thus in about nine months and a half a perfect shaft, exceeding 200 fathoms in depth, was sunk from the surface. So great was the accuracy and skill with which the diallings and measurements for this work were conducted, that after the necessary squaring, Francis's shaft was as perfect as if sunk from the surface only, nor could any irregularity be observed at the junctions of the different portions. The aggregate extent of the earlier workings upon the principal lodes was for a length of 1,700 fathoms, and their depth, on an average, to the 90-fathom level. Assuming the levels to have been driven regularly at every 10 fathoms (which was not strictly the case), this length will give us 17000, fathoms, or *nearly* 20 *miles*.

The aggregate length of the workings in 1835, on the same principal lodes, was 1,200 fathoms, and the depth to which they were carried was on an average to the 200-fathom level. These levels were driven very regularly at 10 fathoms apart, consequently 12,000 fathoms were driven during those workings. *Cusvea*—which became one of the Consolidated mines—was almost a new mine, and here for 200 fathoms the levels were driven regularly from the adit to the 140, making a total of 2,800 fathoms, which, including the ground opened east and west of the deep workings, may probably be called 3,000 fathoms, making a total extension of levels during these workings of 15,000 fathoms; or which, taking into account the distance driven upon the smaller lodes and branches, and also in *cross cuts*, will amount to near 17,000 fathoms, or about 19 miles, thus making the aggregate length of levels in 1835 as more than 33,000 fathoms, or *nearly* 40 *miles*. Considering the depth of these shafts in the same manner, we

may consider these to have been, previous to 1835, about 45 in number (exclusive of shallow ones), and averaging about 100 fathoms in depth, making an average depth of 4,500 fathoms. Twenty of these shafts were sunk during Captain Francis's workings, on an average about 80 fathoms each, making 1,600 fathoms additional. During this period ten new shafts were sunk to a depth averaging 250 fathoms, making about 4,000 fathoms, which, added to the former, gives between 8,000 and 9,000 fathoms, or above 10 *miles*, as the aggregate depth of the shafts in the Consolidated mines.

Within twenty years from the union with the United mines, 37,330 fathoms were driven horizontally, and about 1,800 fathoms sunk in winzes and shafts. This makes the extent of the Consolidated mines at that time as being 63 miles.*

At the end of 1837, the mine having been then at work eighteen years, the account given below was printed.†

Quantity of ore raised and sold, 259,420 tons, the value of which was	£1,845,326
Paid to the lords of the land as dues	76,888
Cost of working the mines	1,450,836
Of which was paid for labour only	758,590
And the profit paid to the adventurers, besides the return of their capital (£65,000)	248,000

The New Consols, subsequently named Wheal Clifford, was united to the Consolidated mines, including the United mines, and this extensive sett was known as Clifford Amalgamated mines.

Wheal Clifford is situated to the east of the United mines. The works at this mine were never very extensive. For example—

In 1833 the mine produced	67 tons copper ore.	
1852	618	,,
1861	6,301	,,

In the following year the extension arising from joining the three setts together, under the title of the Clifford Amalgamated mines, gave rise, of course, to greatly increased returns, which, however, the following statement will show were not very lasting:—

	Ore.	Copper.	Values.	Produce.
1862	14,322 tons	855 tons	£68,475	6
1863	14,273 ,,	896 ,,	68,667	$6\frac{1}{4}$
1864	15,180 ,,	965 ,,	79,702	$6\frac{3}{8}$
1865	15,111 ,,	883 ,,	66,999	$5\frac{7}{8}$
1866	13,961 ,,	784 ,,	50,320	$5\frac{5}{8}$
1867	12,460 ,,	820 ,,	55,825	$6\frac{1}{2}\frac{1}{16}$
1868	10,732 ,,	639 ,,	40,878	$5\frac{7}{8}\frac{1}{16}$
1869	8,309 ,,	587 ,,	35,168	$7\frac{1}{16}$
1870	2,080 ,,	120 ,,	6,743	$5\frac{3}{4}$

On the 29th June, 1870, these important mines ceased working.

The latest account available, prior to the cessation of operations in this extensive set of mines, informs us that the engine-shaft was several fathoms under the 212-fathom level, and that the lode in the shaft was 3 feet wide, producing stones of ore. By extending the 212-fathom level eastwards, it was found that the lode divided, 7 fathoms east of the division, which had been previously noticed in the 200-fathom level, into two regular lodes. The

* John Taylor, "Reply to Observations on the Statement of the Committee of the Consolidated Mines Adventure," 1838. (Printed for private distribution.)

† "Statement of the Committee of the Consolidated Mines Adventure."

north lode in the end was 4 feet wide, worth 8 tons of ore the fathom, while the lode to the south is 3 feet wide, but produced only 2 tons of ore per fathom. It is not easy to account for this remarkable difference in what may be considered as two branches of the same lode. At the same time there were two stopes working in the back of the 212-fathom level, giving 14 tons of ore to each fathom of ground. The 212-fathom level was driven west of the engine-shaft, the lode in the end falling off to 2 feet wide, with occasional stones of ore. In the 200-fathom level driving west the lode was 7 feet wide, giving 10 tons of ore per fathom, and two stopes working in the bottom of the 190-fathom level gave 15 tons of good copper ore per fathom each.

The lode in the 220-fathom level driving east from the United mines boundary was 9 feet wide, yielding 15 tons of copper ore to every fathom. Three stopes were working in the bottom of this level, between the end and the boundary, giving 8 tons of ore per fathom each; and two stopes were working in the back of the 220-fathom level, worth 15 tons of copper ore per fathom, and all the tribute pitches were producing the usual good quantity of ore.

In the United mines district the lode in the 230-fathom level, driving east from Garland's engine-shaft, was 4 feet wide and entirely unproductive. Driving west from Taylor's engine-shaft, the lode produces a few tons of ore. The lode in the 220-fathom level, driving in the same direction, is 4 feet wide, and gives 6 tons of ore per fathom, from which there is a spring of hot water almost continuously flowing. The new works in the United mines district were only occasionally productive. A new shaft, called Buzza, was sunk to the 50-fathom level, and the lode was producing copper ore at the rate of 6 tons to the fathom.

Five pitches were working in this part of these mines at from 2s. 6d. to 6s. 8d. in the £ on tribute. In the 194-fathom level, east from Hawke's shaft on the Great South lode, the ends were generally unproductive.

In the Poldory district and at Wheal Moor sundry trials were made, but none of them proved very successful. From West Poldory to the eastern end in Wheal Clifford there was a course of ore dipping at an angle of about 45°, more than a mile in length. In relation to the heat in these mines it has been asked, "Is it not the constant friction of the water filtering through these long and deep courses of copper ore and mundic that causes the heat of the water, producing a kind of natural sulphuric acid manufactory, but not carrying out the process fully?"

The level in the United mines in which the heat was the greatest at that time (1864) was from the 190-fathom level under the adit to the 230-fathom level. The temperature of the water was then as high as 126° Fah., the air being 121° Fah. At the 208 fathoms the air was 114° Fah. There was a course of ore in this level which was horizontal in one continuous length for 150 fathoms, then there were short breaks comparatively poor, and then fresh courses of ore. The ore being all removed, this level became dry and cold. This looked like chemical action.

The machinery employed in this concern for drainage and other purposes greatly exceeded any similar combination in the world. Eight large steam-engines, their dimensions varying from ninety to sixty-five inch cylinders, and

another of thirty-inch cylinder, were employed for pumping. Eight steam-engines of about twenty-inch cylinders were employed in drawing ore and stuff. Beyond these there was a water-wheel, forty-eight feet in diameter, for pumping, one about forty feet for driving machinery, and five smaller ones for stamping and grinding the ores. Besides these several horse-whims were employed. A writer * says: "Calculating the force constantly exerted by this stupendous accumulation of mechanical power when working at a moderate rate, it may be stated as equivalent to the work of 1,000 horses, which is, however (supposing that it were possible to employ animal power), equal to three relays of horses, required in the twenty-four hours, besides an extra stock for casualties—making the actual number of horses to which the engine-power at these mines is equivalent more than 3,000. It should, however, be taken into account that 'horse-power' so termed by engineers, considerably exceeds the strength of an ordinary horse (according to some authorities by one half), and bearing this in mind, we may probably say that the engine-power employed in these mines is equal to the work of nearly 5,000 horses, and were it exerted to its full extent it would probably be equal to double that number."

The number of persons usually employed at those mines when in activity was about 2,500, of whom between 1,400 and 1,500 were miners working underground. It will be interesting to preserve the

STATEMENT OF THE CLIFFORD AMALGAMATED MINES' ACCOUNT, FOR NOVEMBER AND DECEMBER, 1863.

	£	s.	d.	£	s.	d.
By amount of Wheal Clifford ore sold 3rd and 31st December, 1863	8,074	4	5			
Consols ore sold 3rd December	373	15	1			
Ditto tin	42	4	3			
	8,490	3	9			
Deduct Lords' dues	412	7	5	8,077	16	4
United Mines ore sold 26th November and 24th December, 1863, and 28th January, 1864	4,942	11	1			
Ditto tin sold	91	7	5	5,083	18	6
Sundry receipts	52	3	10			
,, Registration fees	7	10	0	59	13	10
				£13,171	8	8
DEDUCT.						
To labour cost	5,552	13	2			
Tribute of ore	1,009	7	7			
Redruth Railway Co.	250	0	0			
On account of coals imported	1,600	0	0			
Merchants' bills, &c.	3,295	12	7	11,707	13	4
Profit				1,463	15	4
In hand end October, 1863				100	7	8
Balance				1,564	3	0
Deduct dividend, 10s. per share, 17th February, 1864				1,450	0	0
In hand				£ 114	3	0

"*Herodsfoot Mine and Liskeard Lead Mines.*—The lead-mining district in the neighbourhood of Liskeard has of late years been one of considerable economic importance. It is rather a scattered district, extending in the

* F. Burr, *The Mining Review*, 1835.

Killas in a zone about eight miles long, from four miles east-north-east of Liskeard, to about the same distance south-west of that town, flanking on the south the Caradon Granite range, at a distance varying from two and a half to five miles. The lodes which produce lead ore in this zone have an approximate bearing north and south, while the copper lodes to the north of Liskeard course nearly east and west."

The most ancient mine in this neighbourhood is *Herodsfoot*, which has been worked above eighty years, and formerly resulted in large returns from shallow workings in the valley. The present workings were commenced nearly eighty-one years ago, but the mine gradually became poor, and some of the workings had to be abandoned. The lode, both in a north and south direction, encountered the "broken-or-*slidy*-ground," as it is called, which is common to this district. This ground is remarkable; it seems as if the whole had been disturbed, and broken up into a breccia of the nature of "cross courses" or "slides," and the lodes are shattered and lost, although occasionally rich pieces of ore are found. The conditions are similar to those already described in relation to the lodes at Relistian and Herland.

In 1862 the prospects of the mine were very gloomy, and it was almost determined to abandon her entirely, but eventually it was decided that the exploration should be continued, and new workings were opened up, south of the "broken ground." These new workings soon became rich in silver-lead, and the Herodsfoot ore was amongst the most argentiferous raised in the kingdom, some of it selling at £28 7s. 6d. a ton. In the old mine the produce of silver was about 12 ozs. to the ton, and the ore of the new workings frequently gave as much as 70 ozs. to the ton, but at the same time there was a considerable falling off in the yield of lead.

Some of the levels worked were exceedingly rich in lead ore—sometimes containing very little silver—at others being as argentiferous as the richest lead ores of Devonshire. The Herodsfoot lode lies a few degrees west of south, and its average value is from 8 to 9 cwts. of ore per fathom.

The only ends driving in the mine in 1863 were the five that were extended south from the new shaft—the 70, 82, 106, 117, and 127 levels. The 106 and 117 were extended to 60 fathoms south of the new shaft, the other three were only a little south of it. The 70, worked by two men, had a good lode in the end; the 82 had also a rich lode, and was only one fathom south of the shaft; in the 106-fathom end the lode divided into several branches; a cross cut was driven to intersect them all, and the produce has been estimated at about 15 cwts. per fathom. The lode in the 127 end has been interfered with by the disturbed ground.

At the back of the 106, 117, and 127 fathom levels there were thirteen stopes working; those at the back of 127 being on an exceptionally rich lode, one worth some 2 or 3 tons to the fathom, the ore ground being from 2 to 3 feet wide. The lode on part of this stope is of large grain, not very rich for silver, but a little farther north, it suddenly changes to a very fine-grained argentiferous ore.

Up to 1862, the produce of lead ore from this mine was 9,648 tons, which sold for £146,992 13s. 1d.

Ann mine, in the parish of Menheniot, is on the same lodes

as Wheal Trelawney and Trehane. In the northern part of the sett adjoining the Trelawney boundary the ore made quite up to the surface. Southwards the lode is cut off by the disturbed ground. The 160-fathom level communicates from shaft to shaft, and south of Clyma's shaft is extended about 76 fathoms. For the whole of this distance the lode has been productive of lead ore, averaging from 5 to 7 cwts. per fathom, but at some points it reached as high as 26 cwts., while at others it fell so low as from 2 to 3 cwts. The details of the workings in this division of the mine need not detain us. The lode in Wheal Mary Ann, and in Trelawney, is a large and stony one, containing a good deal of fluor-spar and carbonate of lime, with *capels* generally on both sides.

One of the most remarkable features in Wheal Mary Ann is the great run "of *slidy ground*" which cuts off the lode southward. The first effect of this dislocated ground is that the lode is thrown to the right with a bearing west 45° south (Fig. 72). After the *slidy ground* has been intersected, the lode has not again been seen, although the 110-fathom level has been driven considerably south, and east and west. Some branches have been more than once met with, but they always soon disappeared. This mine made all its later returns from below the 200 fathoms, and was eventually abandoned on account of the cost. The returns from these three mines in the ten years before their close were as follows:—

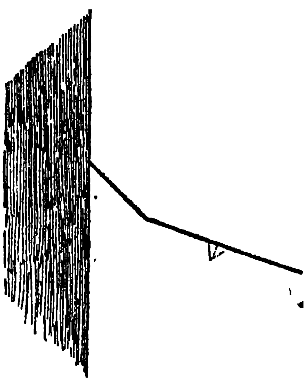


Fig. 72.

	Herodsfoot.		Wheal Mary Ann.		Trelawney.	
	Tons.	cwts.	Tons.	cwts.	Tons.	cwts.
1866	547	9	830	6	879	6
1867	540	2	1,048	13	1,272	5
1868	582	6	1,139	16	756	3
1869	537	6	1,005	18	574	13
1870	508	15	941	16	369	14
1871	473	4	1,047	18	362	8
1872	460	0	1,254	0		
1873	321	1	759	15		
1874	376	9	538	0		
1875	331	1	6	2		

After a repose a fresh start has been made in Mary Ann and Trelawney with every prospect of success. Herodsfoot continued to produce as follows:—

	Tons.	cwts.		Tons.	cwts.		Tons.	cwts
1876	286	16	1878	307	15	1880	451	2
1877	322	15	1879	256	6	1881	435	0

The North Herodsfoot produced 22 tons 16 cwts., and in addition we have now East and West Herodsfoot, East Hony, and Hony and Trelawney United. The striking peculiarity of this lead-producing district is, that all the productive mines are confined to one mass of rising ground, while similar elevations to the east and west are unproductive.

The lode at Wheal Mary Ann has been well described by Dr. C. Le Neve Foster, in a paper which he read before the Geological Society

of Cornwall,* and he describes some peculiarities well deserving especial notice.

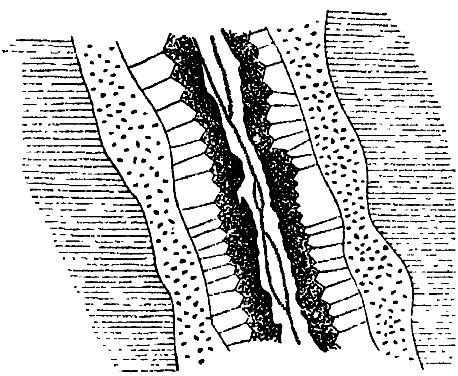
Fig. 73 shows a characteristic section of the lode as seen in the 250-fathom level. We have first of all the two walls of Killas, then proceeding inwards from each wall the *cab*—a sort of chalcedony—then ordinary vitreous crystallised quartz, next galena, and finally chalybite or spathose iron.

Fig. 74 shows another section of a similar lode, the only difference being that the "*cab*" on the footwall contains fragments of Killas.

Dr. Le Neve Foster, from the examination of these sections, deduces the following history of the lodes:—

First, the formation of a fissure, probably accompanied by a shifting of the strata. A succession of open spaces were left, and some parts were more or less filled up by fragments which fell from the walls.

Secondly, deposition of the *cab*, which more or less filled up the fissure



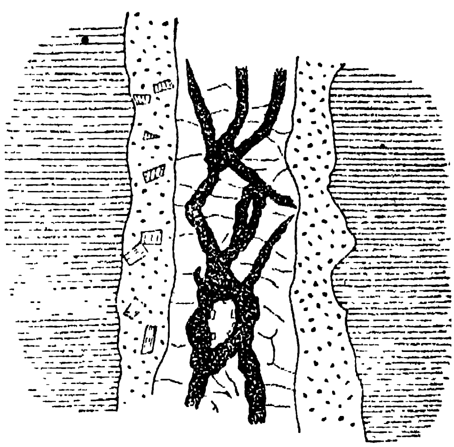


Fig. 73. Lodes at Wheal Mary Ann. Fig. 74.

and cemented any fragments of the walls into a breccia. As would naturally be supposed, this breccia occurs chiefly on the footwall.

Thirdly, re-opening of the fissure. The new line of fracture sometimes occurred in the middle of the filling up of *cab*, sometimes it cut across it, and then followed one of the walls of the original fissure; pieces of the walls and of the previously-formed *cab* lode fell in, and then quartz, galena, chalybite, and calc-spar were deposited successively in the open spaces.

Dolcoath Mine, Camborne.—Mr. Josiah Thomas, in describing Dolcoath, remarks, "that although all the lodes which have been extensively worked have produced large quantities of *copper ore*, yet only the main lode and those lodes to the south immediately connected with it, and which fall into it, have been rich for *tin*. The other lodes, which are smaller, or not connected with the main lode, have nowhere, so far as explored, produced tin enough to be profitably worked. The total length of levels driven on the lodes, together with cross cuts, is about 50 miles in addition to 12 miles of shafts

* "On the Lode at Wheal Mary Ann, Menheniot." By C. Le Neve Foster, B.A., D.Sc., F.G.S. ("Transactions of the Royal Geological Society of Cornwall," vol. ix. part i. 1875.)

and winzes." The usual size of the ends driven is 8 feet high by 6 feet wide. The ground is very hard, and has mostly to be broken by blasting. The cost is upwards of £20 per fathom.

Mr. Thomas, in the year 1870, said: "The mine has been producing about 87 tons of black tin (or tin ore) per month, or 1,050 tons per year; in order to obtain which, we raise and stamp about 1,000 tons per week, or 52,000 tons per year; so that the average produce of our tin stuff, as raised from underground, is as near as can be 2 per cent. of tin ore; or, in other words, only one part in 50 (except a little arsenic) is of any value, the other 49 parts being worthless.

"To work so deep a mine (nearly 2,000 feet from surface) and to raise so large a quantity of tin, from so hard a rock, is necessarily attended with great labour and expense. There are two steam-engines, respectively of 85 and 60 inch cylinder, employed in pumping water from the mine, and three steam-whims drawing *stuff* (but of these one only works occasionally). There are also two steam-engines employed in stamping, and one in working the 'Man-Engine' for lowering and raising the miners.

"Our *stuff* is drawn to the surface by *kibbles* and wire ropes. The kibble will contain one ton of stuff, and the ropes are made of steel wire $3\frac{1}{4}$ inches in circumference. One steam-whim draws from two shafts at the same time, there being one kibble in each shaft; so that whilst the empty kibble is being sent down in one shaft, the full kibble is being drawn to the surface in the other. In ordinary working we can easily draw with one steam-whim from the bottom of the mine 6 tons per hour.

"On being drawn to the surface the rocks are 'spalled' or broken into small pieces of two or three inches in diameter, to prepare it for being stamped. The large rocks are broken into smaller pieces by men, but the 'spalling' is principally done by girls, with small steel sledges, at a cost of about $4\frac{1}{2}$d. per ton.

"The particles of tin being small it is necessary to reduce the stuff to a very fine powder. This is done by two steam stamps, one having 120 heads and the other 60 heads. In the winter there are 20 heads worked by water power. By means of these stamps the stuff is reduced so that the particles will pass through a grating with 150 holes to the square inch, or if the particles of tin are large a rougher grate is used. The ore is dressed entirely by 'buddle' and 'kieve.' The 'centre cone buddle' is the one generally adopted, the one used at Dolcoath being from 16 to 22 feet in diameter, and the diameter of the central cone being from 5 to 8 feet, according to the nature of the stuff to be dressed. On the top of the centre is a funnel with an iron plate attached for distributing the stuff equally over the centre, and also three or four arms for brooms or sweeps, which, together with the plate and the funnel, are made to revolve by machinery driven by a water-wheel, whilst around the buddle is a trench filled with water into which, whilst the buddle is being worked, the tails or worthless parts of the stuff are washed away after being separated from the tin *buddling*. The 'stirring' and 'packing' in the kieves are also performed by water power.

"The ore is afterwards calcined, to separate the arsenic which is usually combined with tin ore. For this purpose Brunton's calciners are generally

used. The arsenic is driven off in fumes and deposited in flues; the tin is left behind, and again dressed in buddles and kieves. When it has thus been freed from waste it is ready for the market, and the tin ores of Dolcoath produce nearly 70 per cent. of metal."

Already some remarks have been made on the supposed influence of the direction or bearing of the lode on the production of metallic ores. If there is any sufficient confirmation of this, it at once establishes a close relation between the deposition of ores and terrestrial magnetism. We know that iron, nickel, and a few other metals are what is called magnetic; that is, they place themselves at right angles to the direction of an electric current, while bismuth, and most other substances, have a tendency to arrange themselves across the line of magnetic force. The consequence of this is the tendency of a magnetised bar of iron to point to the North Pole; or, in other words, to arrange itself north and south. On account of this property we employ a magnetic-needle in our surveying instruments, to guide us in the true direction of the lode upon which excavations are being made, and to secure correct results in our surveying operations.

Dr. Faraday called one set of metals—those which are magnetic, as iron is—*magnetic bodies*; and those which exhibit a tendency to arrange their long axes at right angles to the direction taken by a bar of iron, *dia-magnetic*. This will be better understood by a diagram:—

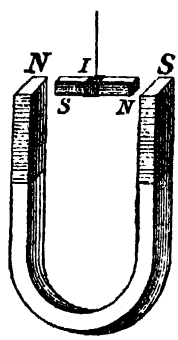


Fig. 75.

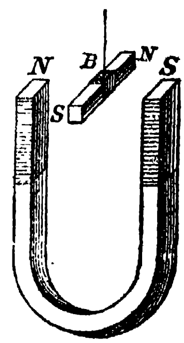


Fig. 76.

N and S represent the poles of a horse-shoe magnet (Fig. 75). If a piece of iron is hung up between the poles, the active force compels the bar to arrange itself so as to join the two poles as I does, the North Pole N being opposite the pole S, and the S pole being opposite the N pole of the magnet. If, on the contrary, a bar of bismuth is so suspended, it arranges itself at right angles to the direction of the magnetic force, as shown at B (Fig. 76). The magnetic force is supposed to pass *through* bodies thus constituted, and they are called *dia-magnetic*, the prefix *dia* having the same meaning as in diameter. It has been already stated that the sun establishes an electric disturbance, from every point, on which its rays fall, and this disturbance, or current, traverses the Earth from the east to the west. A magnet is compelled to dispose itself so that one pole points northward, and the other to the south, or across the line of the solar electric current. The diamagnetic bodies naturally tend to take a direction at some angle, nearly agreeing with that of the electric flow.

This brief explanation of a very refined experiment is given, for the purpose of explaining the principle, upon which it may be supposed, that direction has something to do with the deposition of mineral riches in the veins, or cracks which take a certain bearing, in relation to the magnetic meridian.

Captain Charles Thomas, who was for many years the managing agent

of Dolcoath mine, in some lectures delivered by him at Camborne, and subsequently published, directed the attention of his hearers—chiefly young miners—amongst other important matters, to "the direction or bearing of the lode in your sett." * His words are as follows:—

"This is of greater importance than is generally supposed. Where the direction is wrong, whatever other favourable indications may be present, I have never known a profitable mine. The best direction for different metals varies very greatly. In the following remarks I take the present *magnetic line*, which is about 24° west of true north.†

"Tin lodes varying from 30° north of east to 30° south of east (magnetic), a range of 60°, have been found profitable for working. Copper lodes with a similar range of 60°, but varying from 10° north to 50° south of east, have been found profitably productive. Lodes varying from 5° north to 25° south

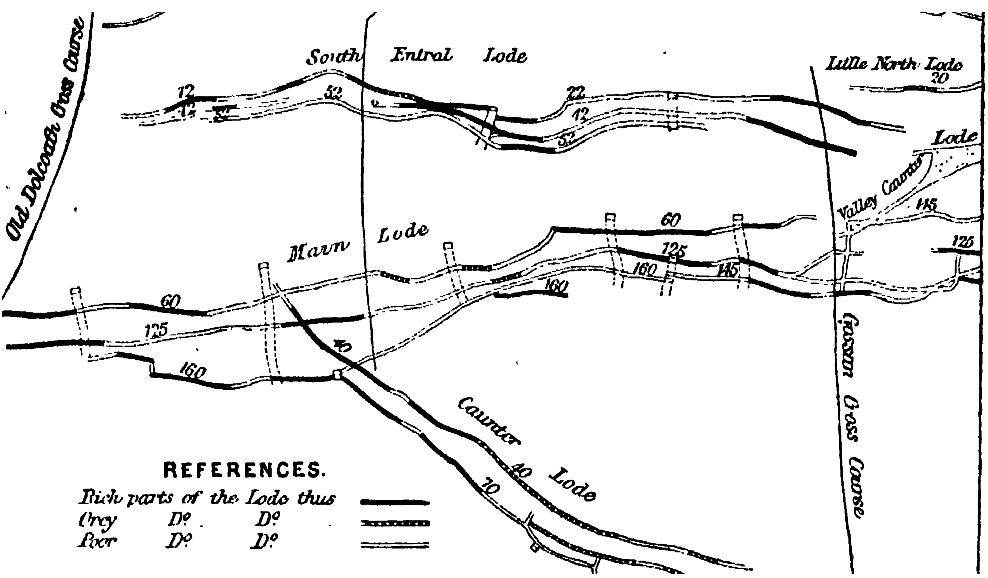


Fig. 77.—Productive Parts of Lodes at Dolcoath.

of east have, however, yielded the greatest quantity of copper ores. In the lodes whose direction is from 25° to 50° south of east very *rich* ores are found, but not in very great quantities. In lodes bearing more than 10° north of east (or 34° north of *true* east) the ores are generally very poor.

"The best direction for lead lodes is from 10° west of north to about 40° east of north. I believe the above to be a statement of facts as found

* "Remarks on the Geology of Cornwall and Devon in connection with the Deposits of Metallic Ores, and on the Bearings of Productive Lodes." By Captain Charles Thomas, of Dolcoath Mine. Camborne: 1859.

† This was in 1859. The magnetic elements for 1883, at the Royal Observatory at Greenwich, are—

Declination (or variation of the compass)	18° 15′ west.
Inclination (or dip of the needle)	67° 32′
Horizontal force (measured in British units)	3·92
Vertical force " "	9·48
Total force " "	10·26

To find the true north in or near London by means of a magnetic-needle the compass must be so placed that the north end of the needle points about 18° 15′ west. The north and south points of the dial will then be in the true meridian nearly. The magnetic variation along a line passing from the south of Dorsetshire to Whitby will be 19° 12′ west, and a line passing from the river Tamar to Durham will be 20° 12′ west.

existing in the mines of Cornwall and Devon. The exceptions are exceedingly rare, and when they occur the cause can be ascertained. The St. Just district, I think, affords the only apparent exception to the rule, and some of the deposits of copper ore even there may be satisfactorily accounted for in accordance with this rule. I have found in numberless instances a rich course of copper ore while the direction of the lode was south of east, due east, or 5° north of east; but a turn in the lode taking place of 5° or 7° farther north, the lode would not pay for working." The diagram, Fig. 77, showing the productive parts of the lode for copper ore in Dolcoath mine, illustrates the hypothesis of Captain Charles Thomas.

The *Minera* mines—Denbighshire—have been celebrated since the commencement of the eighteenth century for their remarkable production of lead ores, and they are yet amongst the first of the British lead mines, for large returns of ore. In 1881 they produced 1,250 tons of lead ore, containing 8,120 ounces of silver of the value of £12,870, and 5,468 tons of zinc ore of the value of £21,050.* The district about them is equally remarkable, for within a radius of five miles from the mines, we find most of the common British minerals of commercial value, except tin ore, and the representatives of every strata occurring between the Lias and the Cambrian—a portion of the English series of stratified rocks, of far greater interest and value, in an economic sense, than all the others.

Disregarding the Roman workings of these lead deposits, and the subsequent workings which are alleged to have occurred at various periods antecedent to the year 1700, a brief summary only is given of the more recent operations. About the year 1710 the first regular and systematic mining operations seem to have been commenced at Minera, beginning in that portion of the present sett then known as the West End mines. Here the near proximity of the ore-bearing strata to the surface, and the outcropping of the lower measures, appealed at once to the miner, and extensive workings were established on several veins, and split portions of the main lodes, as well as in the *flats* which abound in those particular strata. The gradual extension of these operations eastward, following the dip of the measures, induced other parties to make a trial of the still more eastern ground, and for many years the results were profitable to both companies. From 1720 to 1824 (when the different leases terminated) the fortunes of both setts were chequered, as they fell into various hands; yet the workings seem always to have been attended with a full measure of success. About 1816 the West End mines finally stopped, not so much, however, from poverty as from the enormous influx of water, which frequently flooded the mines and entirely prevented the carrying on of regular operations; and in 1824 the suspension of the East End mines followed from the same causes, the "bottoms" being still rich and productive.

There are two principal veins at Minera, the Old vein and the Red vein, both coursing almost the entire length of the property, which is about two miles long and half a mile at the extreme breadth. The Old vein was for a considerable period believed to be the only vein in the East End mines.

* "Mining and Smelting Magazine," vol. ii.

This vein is really a true fault, which has become filled with mixed mineral matter. At Andrew's shaft, about the centre of the property, it has a down-throw of 410 feet to the north, the Millstone Grit and shales being to the one side of the vein and the Limestones on the other. The throw of the fault varies, rapidly decreasing as it goes westward, while going eastward, for some distance at least, it seems to remain somewhat constant, attaining a maximum near Taylor's engine-shaft.

This vein, being a fault fissure, the deposits of ore, as in all such cases, are very irregular, and exceedingly "bunchy," sometimes swelling out into immense masses of ore, or *gangue*, and at others becoming quite poor and *nipped up*. The vein is so small and poor at Andrew's shaft, that in driving the deep adit level on the vein, for scores of fathoms, it required the keenest and most practised eye, to discover that a vein existed at all, and again in the short distance of two or three fathoms it suddenly opened out to a large size, producing a rich bunch of ore. The Old vein is also subject to many sudden changes of this kind.

The general uncertainty of the occurrence of these runs of ore has led to the adoption of a regular system, of cross-cutting the lode, at very short intervals, from which excellent results have been obtained. Very frequently, after following a branch of ore worth £60 or £80 per fathom, which, with its accompanying veinstone, is enclosed between two faces, resembling the regular walls of a lode, if a cross cut be put out, it will be found to pass for two or three fathoms through a confused mass, more or less brecciated—of Limestone, hard shale, and *gangue*—when another equally valuable branch of ore will probably be found, also enclosed between regular faces. A continuation of the cross level has even at times discovered another and third branch of lead ore under similar circumstances. If continued, the cross cut would ultimately reach the hard black shales, showing the limit of the veins, for such is the nature of the country, north of the Old vein in the East End mines.

The dip of this vein is about north-east (true), the angle averaging 80°. It therefore courses about south-east and north-west. Previous to splitting up, as it does in the West End mines, it takes a slight curve to the west, coursing here about north-west by west (true). Towards the Grand Turk and Busy Bee shafts it bifurcates, and branches run off, which may be considered true veins; indeed, it is here that, for the first time, anything of a character analogous to the regular lodes of Cornwall is found. These offshoots course regularly, have distinct walls enclosed by true Limestone country, and they have in many instances been remarkably productive. Although this old vein may, in a mining sense, be considered as a lode, yet its real character is an ordinary *fault* containing mineral matter. As the fault caused by this old vein continues west, it decreases very considerably in its throw. The Limestone here is the surface rock on both walls of the veins. The thickness of the Limestone varies, however, materially, and frequently most irregularly, being seemingly to a great extent determined by the vein, which may traverse it at the point of observation, every vein at Minera having some throw, or dislocating effect, on the strata. In this respect we trace an analogy between the Minera veins of Denbighshire and those of Alston Moor.

Farther west the veins undergo another change; they become themselves

much poorer, but act as feeders to numerous "Flats," "Pipes," or similar irregular deposits. Under these conditions some remarkably fine masses of ore have been found, and the enormous cavern-like excavations, in Maes-y-ffynnon and Llyn Ddu, sufficiently attest the truth of the statements which have been handed down to us in respect to them. In this part of the mine the ground is a hard and compact white Limestone, and the ores' deposits are almost totally unaccompanied by veinstone of any kind. The veins here are very open, and form channels for the passage of the immense quantities of mud, sand, and water which in rainy seasons flow through them.

There is a marked difference in the character of the eastern and western portions of the Old vein. Near the Meadow,—or extreme eastern shafts in the upper levels,—this vein occurs in black shales and Slates belonging to the Lower Coal and Millstone Grit series, and is usually very poor; deeper it intersects the Carboniferous Limestone, and becomes to some extent productive, but instead of lead deposits we find the lode filled with large quantities of brown blende. This ore is intermixed with pulverulent and massive quartz, and contains many large stones of galena. Farther westward, between Taylor's shaft and Ellerton's shaft, the Old vein becomes largely productive. The West End mines, the Old vein, as well as the cross and caunter lodes, which are found in this part of the Minera mines, have some shale, a little blende, and much calc-spar, as their characteristic mineral; quartz does not occur in any quantity, and but little lead is found.

Besides the Old vein there is another lode of extreme productiveness which in the East End mines is called "North vein," and in the West End mines "Red vein." The North vein, in some of the orey portions, is extremely cavernous. At Meadow Shaft there is a powerful deposit called the "Marion String," crossing from the Old to the North vein. Westward of this, nothing has been seen of the lode for 800 yards. Passing the whole of the ground lying between Taylor's and Andrew's shafts, which on the Old vein was so valuable, we reach the point where the North vein is seen for the first time; here it was but moderately productive, but being followed westward yielded large returns of ore. Some of the bunches of galena were of enormous size, so that it has not been rare to see parcels of vein stuff, 60 tons in weight, drawn from these workings, containing not more than 15 per cent. of foreign matter. This deposit of ore extended as high as the 100-yard level, and has been quite as rich in its upper as in its lower zones. In the neighbourhood of Andrew's shaft we observe the "parallelism of veins" distinctly exemplified in the large measure of metalliferous wealth stored up in the same belt of ground.

At *Maes-y-ffynnon* we find the lode absolutely poor, a mere fissure in the strata, and free from even a moderate quantity of veinstone or *gangue*. The "cheeks of the vein" here consist of the bottom measures of the Limestone, with some Millstone Grit, the whole resting at the depth of 100 yards upon the Silurian Rocks.

It is a point of interest to find the *Brymbo main coal* approaching the metalliferous lodes of Minera. It would appear that the North vein ultimately attains, approximately, the same amount of dislocation as the Old vein has at this point, the *Old vein* diminishing to a *heave* of small importance,

when fairly in the Coal Measures. This point of ultimate change is about two miles from Taylor's shaft. Here the two faults are uncertain in their character, but their existence admits of no doubt. They have a combined throw of about 120 yards, and form a channel of faulty ground which divides the Brymbo and the Ruabon coal field, and which is known to course from Minera through Pentre-Bychan. At this point the Brymbo main coal—a little to the east of Pentre-Bychan—is probably at least 200 yards deep, while on the other side of the fault it does not, in a corresponding position, exceed 80 yards from the surface.

To the north-east of the North vein the ground is greatly disturbed, the edges of the strata, impinging against the vein, being broken and disturbed in a high degree. No regular coal has been noticed, only small lumps of carbonaceous mineral, but the strata, composed of shales and thin Sandstones intermixed, the former preponderating, belong to the true Coal series, the fossil flora of the series in this district, having probably all of its genera represented. The shales give evidence of a sliding action, and show the peculiar polished faces, *slickensides*.

The rich ore-bearing vein of Minera has been stated to be a true fault. It forms the northern throw of a faulty channel of ground separating the Coal and Millstone Grit Measures from the Mountain Limestone. At the extreme east, near the "Meadow Shaft," as it is called, the lode enters the *Lower Coal Measures*, where it appears to be split into several branches. These are found in *black shales*, and contain large and beautiful iridescent cubes of galena, associated with quartz, which frequently leave pseudomorphous impressions of their crystals. The deepest point in the Minera is Roy's shaft, 315 yards below the surface. In the year 1876 the Darlington rock-boring machinery, and the blasting of the shot-holes by electricity, were introduced, since which the power drills continue to do good work with very beneficial results as regards increased speed of driving and economy in working the mine.*

The following statement of the financial position of the Minera mines, as an example of successful mining, will be of interest:—

					£ s. d.
The capital of the undertaking is					45,000 0 0
The produce raised and sold from 1850 to end of 1882 consists of 108,369 tons 3 cwt. of lead ore and 63,784 tons 19 cwt. of blende, which realised together					1,692,324 14 2
					£1,737,324 14 2
The payments include—					
Promoters for leases of mines			£7,500 0 0		
Freehold landed property			712 18 1		
			8,212 18 1		
Royalties		£147,869 0 10			
Mine costs		954,941 8 3			
		1,102,810 9 1			
Dividends	£615,916 5 0				
Reserve Fund	8,740 7 8				
Cash in hand	1,644 14 4				
		626,301 7 0			
			1,729,111 16 1		
					£1,737,324 14 2

* "Mineral and Geological Sketch of the Minera Mining Field, Denbighshire, North Wales." By George Darlington. ("Mining and Smelting Magazine," vol. ii. 1842.)

Within the limits of the *Denbighshire district* the following setts have been wrought—Bodidris, Bryn Derwyn, Cefn-y-gist, Denbighshire Consols, Dyffryn Mid, Lady Ann, Lead Era, Minera Consols, Minera West, Minera Mountain, Nant Uchaf, Pont-Du, Waenlas, Park, Pool Park, and Union and Boundary.

These mines have not been very productive; the produce of lead and zinc ores in 1881 being as follows:—

	Lead Ore.			Zinc Ore.		
	Tons.	cwts.	qrs.	Tons.	cwts.	qrs.
Bodidris	31	8	0		—	
Bryn Derwyn	10	4	0		—	
Cefn-y-gist	6	10	0	3	5	0
Denbighshire Consols	100	12	0		—	
Minera Consols	7	1	0		—	
Minera Mountain		—		16	0	0
Minera West	0	10	0		—	
Pont-Du	6	0	0		—	
Union and Boundary	12	10	0		—	
Park		—		100	0	0
Pool Park		—		15	0	0

A brief description of some of these mines, where they present any peculiar character, must be given.

The *Park* mines have been wrought through an extended period with very variable success. They are situated west-south-west of Minera. The veins worked in those mines are entirely distinct from those in Minera with one exception. The *Ragman* vein is a *caunter* to the Minera lodes, and traverses the eastern portion of that sett. The surface of the Park mine is at an elevation of nearly 500 feet above the level of the railway at Minera, which corresponds with the back of the Old vein. The Park mine has been chiefly worked upon one vein, which courses north-west by west, and underlies pretty regularly at about 15° from the perpendicular, being occasionally broken by the shale beds. There are some other small veins in the Park sett which appear to be branches of the main lode. The *flats* and *dry feeder* veins of Minera have been expected to run into the Park mine, but they have not been determined. The veins in the Park sett are chiefly composed of lead ore, calamine, calcareous spar, quartz, blende, and clay. The carbonate of zinc, which has been occasionally found, appears to take the place of the blende, which is found so plentifully in Minera.

Pool Park mine appears to have been worked upon a vein which is intimately related to that in the Park mines. The ore occurs in irregular masses, and has sometimes been found in *pipe* or in *pillar* deposits, of great purity and richness.

Minera Union is on the north-western outcrop of the Mountain Limestone, the strata having an average thickness of about 200 feet. The veins in this mine resemble in most respects the mineralogical character of the central portion of Minera. The veins have been usually productive, and the measures through them are regular and even in their character; they crop out in the eastern end of *Central Minera*.

Central Minera lies to the westward of the Union mine, close by the "Great Denbighshire Fault." The veins are very irregular, but a few fine bunches of lead ore have been found in them. The *Ragman vein* is here proved

to be a *caunter* to every vein in the entire district, coursing almost north and south. This great vein is the most marked, and the poorest, in the district. It cuts into this sett, but, unless in some of its offshoots, it has never been productive. The *Ragman* is traceable for two miles, as a most regular lode. Its strike, underlie, thickness, and mineral contents are all remarkably uniform. Its contents are chiefly sand, clay, and matter eroded from the surrounding rock, and carried by water into this fissure, through the numerous cracks and cavernous watercourses which exist in the Mountain Limestone on its western outcrop. There is so great an analogy between the *Ragman* and the great Flintshire fault, through which the stream discharged at Holywell flows, that they may be referred to the same set of geological phenomena. The causes which have led to the enrichment of the Minera lodes, and those in the neighbouring mines, are not satisfactorily determined. A change of underlie, or branches, or feeders flowing in from the south, often produces bunches of lead ore. Large quantities of lead are always associated with certain well-marked strata, and always follow them in their eastern dip. The occurrence of *black shale* and pulverulent quartz are reliable indications of wealth. In some places calamine in the upper part of the lode is a satisfactory indication of lead ore in depth, and blende under similar circumstances is, say some authorities, "an invariable guide to wealth."

Most of the veins in this district are thought to be contemporaneous. The same movement without doubt produced all the parallel fissures. This disturbance occurred subsequent to the deposition of the coal strata, for the Minera veins, which are co-existent with the others, break through the Coal Measures as faults.

Anglesea Mines.—Parys Mountain—which is a portion of Trysclwyn—derives its name from a Robert Parys, who was chamberlain of North Wales in the reign of Henry IV. (Pennant, in his "Tours in Wales," says doubtingly of this, "There was another of the same name in the reign of Edward III.") From what has already been stated, it will be evident that this district was worked for copper in the days of the Romans, if not by the Britons. In 1762 Alexander Frazier was in Anglesea seeking for mines, Sir Nicholas Bayley gave him so glowing an account of Parys Mountain that he was induced to make a trial. Ore was discovered, but before any quantity could be raised the mines were flooded, and their means for removing water were so inefficient that the works were suspended. In 1764 Messrs. Roe and Company of Macclesfield applied to Sir Nicholas Bayley for a lease of Penrhyn Du in Carnarvonshire, which was granted only on the condition that they leased a portion of Parys Mountain and made a fair trial of the mine. They commenced operations, and ore was obtained, but the cost was excessive. These adventurers were great losers, and they resolved to abandon the mine. Orders were given to their agent, but he resolved on a final attempt at discovery. He divided his men into ten companies, and directed them to sink shafts in several places. Near a spot, called the *Golden Venture*, led, it is said, by a spring to believe that a body of mineral must exist there, they sunk a shaft. On the 2nd of March, 1768, they discovered the mass of ore, which has been worked continuously since that time. Pennant informs us that "soon after this discovery the Rev. Edward

Hughes, owner of part of the mountain in right of his wife, *Mary Lewis, of Llys Dulas*, began to work, so that the whole treasure is the property of Sir Nicholas Bayley* and himself.

Pennant gives an interesting but not very exact account of the Parys mine. "The body of copper," he says, "is of unknown extent. Several years ago" (written 1810) "the thickness was ascertained by driving a level under it, and it was found to be in some places 24 yards. The ore is mostly of the kind called by Cronstedt *Pyrites capri flavo viridescens* (yellow copper ore, or copper pyrites, some of it being the iridescent variety called peacock copper), and contains vast quantities of sulphur. . . . . There are other species of copper ore found here. Of late a vein of *Pyrites cupri griseus* of Cronstedt (grey copper ore), about 7 yards wide, has been discovered near the west end of the mountain; some is of an iron grey, some quite black; the first contains 16 lbs. of copper per cwt., the latter 40 lbs. An ore has been lately found in form of loose earth, of a dark purplish colour, and the best of it has produced more than 8 in 20. Some years ago above 30 lbs. of native copper was found in driving a level through a *turbery* (a turf field); some was in form of moss, some in very thin leaves. The ore is quarried out of the bed in vast masses, it is broken into small pieces, and the purest part is sold raw, at the rate of about £3 to £6 per ton, or sent to the smelting-houses of the respective companies to be melted. Mr. Hughes has great furnaces of his own at *Ravenhead*, near Liverpool, and at Swansea, in South Wales. An idea of the wealth of these mines may be formed by considering that the Macclesfield Company have had at once 14,000 tons of ore upon bank, and Mr. Hughes 30,000 tons. . . . . The ore is not got in the common manner of mining, but is cut out of the bed in the same manner as stone is out of a quarry. A hollow is formed in the solid ore open to day, and extends about 100 yards in length, about 40 yards in breadth, and 24 yards in depth. The ends are at present undermined, but supported by vast pillars and magnificent arches, all metallic, and these caverns meander far underground (Fig. 78). These soon disappear, and thousands of tons of ore begotten from both the columns and roofs. The sides of this vast hollow are mostly perpendicular, and access to the bottom is only to be had by small steps cut in the ore; and the curious visitor must trust to them and a rope till he reaches some ladders which will conduct him the rest of the descent. On the edge of the chasms are wooden platforms which project far, and on them are windlasses by which the workmen are lowered to transact their business on the face of the precipice. There suspended they work in mid-air, pick a small space for a footing, cut out the ore in large masses, and tumble it to the bottom with vast noise. In such situation they form caverns (in which the men rest during explosion of gunpowder in blasting), and there appear safely lodged, till the rope is lowered to convey them up again. Much of the ore is blasted with gunpowder, eight tons of which, I am informed, is annually used for the purpose."

It is desirable that a careful account should be given of all the known

* Afterwards Earl of Uxbridge, now Marquis of Anglesea.

conditions under which this extraordinary deposit occurs. The drawing given on page 452 (Fig. 83) faithfully represents the *Clay Shaft* lode, and four other important mineral veins, as they approach the surface, and enter the Great Open Cast: giving a correct idea of the conditions of these deposits. The greyish-blue Clay-Slates immediately beneath become more and more quartzose as they approach it; certain portions transfused with silicious matter, displaying a flinty character, whilst other parts are made up of Slate and quartz in distinct and separate laminæ; several large and exclusively silicious beds of schistose structure enclose, here and there, bodies of massive quartz, and broad bands of greyish hornstone occur at intervals. The Slate directly overlying the ore is generally brownish, but—exhibiting various colours within short distances—it passes gradually into a normal blue. Many beds are sprinkled and veined with silicious substances, but these rarely accompany the thick conformable layers of metalliferous quartz which have been largely worked in the northern parts of the mines.

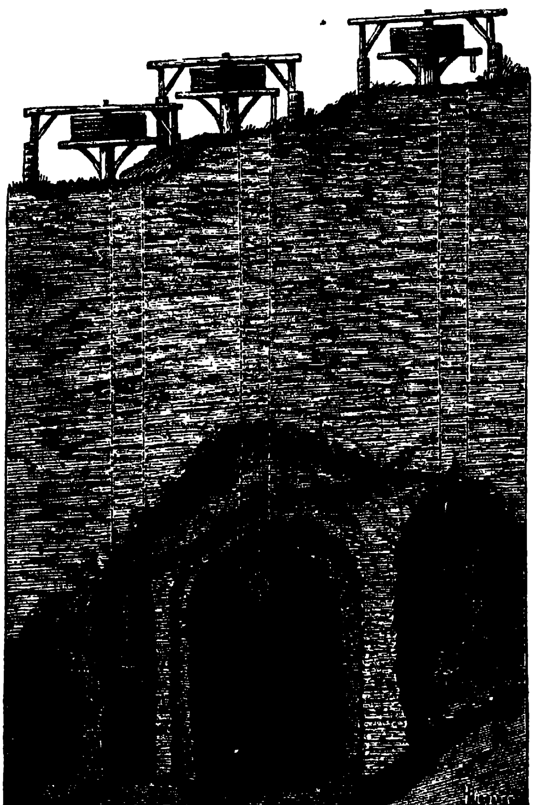


Fig. 78.—Caverns worked from the Open Cast.

South of the great metalliferous deposit, where little or nothing of much value has yet been found, the planes of cleavage, maintaining a tolerable regularity, bear nearly east and west. In other parts of the district, however, their directions are less uniform; for the average of their many large flexures in the Mona mine towards the north-east is 12° to 30° south of east to north of west, near the boundary of the mines, they range about east and west, and in the Parys works, on the north-west, some 15° to 25° north of east to south of west. Moreover, the wide floor of copper-bearing quartz, worked to a greater or less extent in various parts of both mines—as in the Carreg-y-doll lode—is subject to like flexures; and the smaller metalliferous beds, severally known as the Clay Shaft lode and the Charlotte lode in the east, as the North Discovery lode towards the west, and as the Black Rock lode throughout, also conform to the undulations in their respective neighbourhoods. The relations between the great metalliferous deposit and the rocks adjoining it are not now very readily discerned; its general direction, however, is some 12° to 15° north of east to south of west, and

its dip, like the dip of other productive beds of quartz and the cleavage-planes of the neighbouring Slate, ranges from 50° to 84°, and averages, perhaps, 65° towards the north. The formation is intersected by joints of two series, which, differing both from the copper-yielding beds and from the cross veins (flucans) in direction, bear 25° to 35° west of north to east of south, and 30° to 40° north of east to south of west respectively. Two cross veins traverse the district, namely, the eastern, or Carreg-y-doll, which ranges some 5° to 15° east of north to west of south, and the great, or western, cross course which takes a nearly meridional bearing. Both these cross veins heave the smaller productive beds they encounter towards the left hand, and to the side of the greater angle, the Carreg-y-doll cross course displacing the Charlotte lode but slightly, the Carreg-y-doll lode about 12, and the Black Rock lode nearly 8 fathoms; whilst the western cross course dislocates the Carreg-y-doll lode as much as 30 fathoms. Both cut through the great metalliferous deposit also, but the extent of any *heaves*

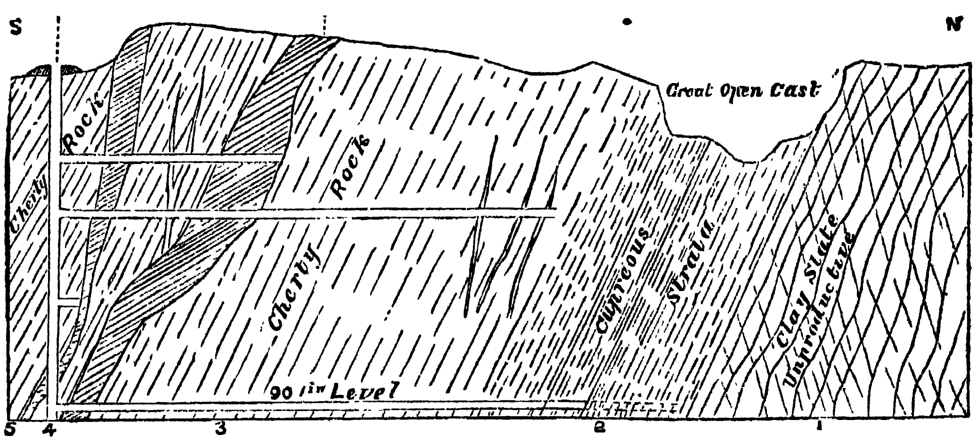


Fig. 79.—Parys Mine—Section across Strata.*

they may have occasioned is concealed by the rubbish which now covers the sides of the openings wherein it was formerly wrought.

The North Discovery lode varies from about 2 to 8 feet, the Carreg-y-doll lode from 1 fathom to nearly 10 fathoms in width; both enclose conformable masses of Slate (*horses*), and consist in great measure of quartz, quartzose Slate, chlorite, and disintegrated felspar, mixed, however, with earthy brown iron ore as well as with smaller quantities of native copper, earthy black copper ore, the sulphide of lead, and other minerals near the surface, with yellow copper ore and specular iron at greater depths, and with larger or smaller proportions of iron pyrites throughout.

The great metalliferous deposit appears not only to have occupied the whole space between the Clay Shaft lode and Black Rock lode for a considerable distance, but also to have extended some way north of one and south of the other.

It has been wrought open to the day for about 90 fathoms on the line of

* For this and the two following woodcuts we are indebted to "A Treatise on Metalliferous Minerals and Mining," by D. C. Davies, F.G.S.

its strike and more than 140 fathoms in extreme width in the hillside open cast, and 210 fathoms on the line of its strike and 90 fathoms in extreme width in the great open cast, to a depth of 18 fathoms and for an area of 5·331 acres in the former, and to a depth of 23 fathoms and for an area of 12·131 acres in the latter, and to greater depths for short distances in both. The open casts are separated by a body of veinstone, varying from 10 to 50 fathoms in thickness, whence small quantities of copper ore are still extracted.

Some idea may be formed of the value of these mines in their earlier workings from the following figures:—

In 1778	both mines	did not exceed	1,200	tons copper.
,, 1784	,,	,,	3,000	,,
,, 1785	,,	,,	2,300	,,
,, 1798	,,	,,	1,700	,,
,, 1799	,,	,,	1,900	,,

The depths of these mines in several parts are—Middle lode, 150 fathoms; Carreg-y-doll, 124 fathoms; Great Open Cast, 75 fathoms; North Discovery lode, 150 fathoms.

The principal earthy ingredients—as in smaller productive beds on the north—are quartz and quartzose slate, through which chlorite is thinly and

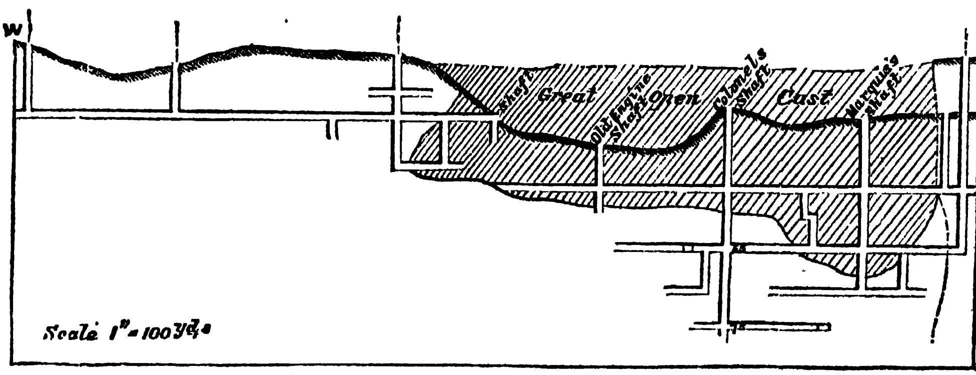


Fig. 80.—Section of Workings in Parys Mine.

rather unequally sprinkled; towards the east, however, and especially near the (*footwall*) lower side, buff-coloured felspar is also abundant. Thin fissile layers of blackish-blue slaty matter interlie the other constituents, dividing them into ill-defined beds, parallel to the adjoining rocks. Shallow parts of these mines have afforded much earthy brown iron ore (*gossan*), containing nests of earthy black copper ore, and small cavities incrusted with the carbonates of copper and the sulphide of lead. Beds, laminæ, interlacing veins, isolated bodies, single crystals, and disseminated grains of iron pyrites even yet abound in the quartzose and slaty portions of the mass. Galena occurs in some and blende in other parts of the formation; and occasionally the intractable association of both these with iron and copper pyrites has been plentiful. Native copper, earthy black copper ore, vitreous copper, and purple ore have been frequently obtained; the principal produce, however, has always been copper pyrites. Great quantities were, of course, scattered through the earthy matrix; but during three months in the year 1787 one party of workmen extracted 2,931 tons of good

copper ore and only 92 tons of which was waste." In both the open works several large masses of quartzose Slate (*horses*), interlaid by laminæ, and intersected by thin veins of iron pyrites, have, by the removal of the copper ore which surrounded them, been left standing as isolated crags. (See Fig. 82.)

Between the two enormously rich portions (*bunches*) of the great metalliferous deposit wrought in the "hill-side open cast," and the "great open cast" respectively, a body of comparatively unproductive—yet slightly orey—quartzose veinstone intervenes; whilst, like many of the largest courses of tin and copper ore in Cornwall, each of them is intersected by a cross vein. Both the cross veins partake to some extent the character of the ore ground they traverse. For the most part, however, they consist of slate identical, in both composition and structure, with the rocks (*country*) adjoining, that is to say, they, as well as several of the cross veins of Cornwall, are mere slices of the strata containing little or no ore.

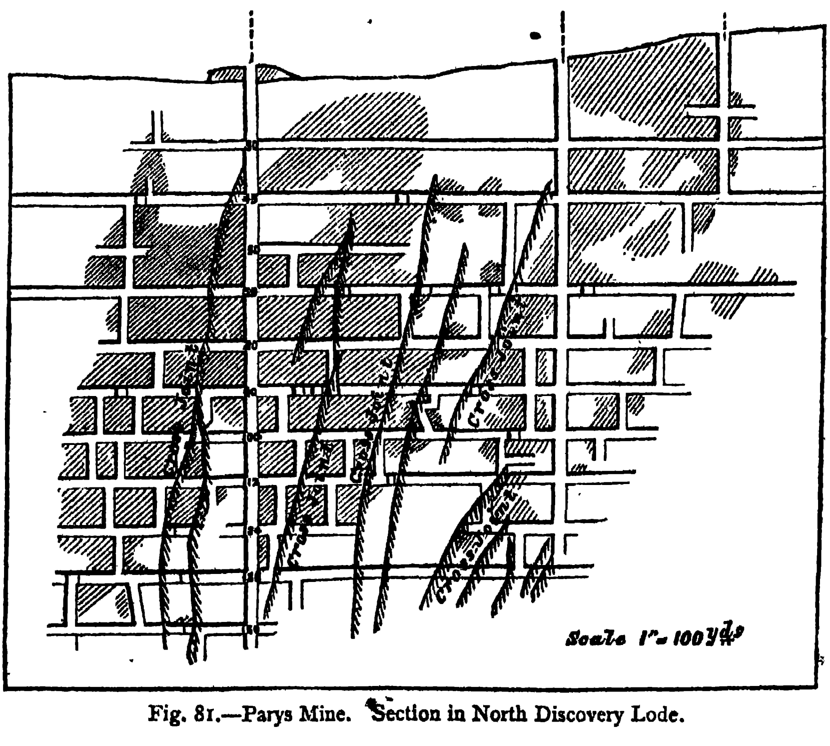


Fig. 81.—Parys Mine. Section in North Discovery Lode.

The richest part of the North Discovery (*bed*) lode is intersected at about right angles to its course by two nearly vertical joints; but the poorer portions are traversed by several such seams, all which dip towards the west.

The body (*courses*) of ore, both in the great deposit and in the North Discovery lode, has also a westerly dip endlong, but at a lower angle.

To a depth of 18 fathoms in one part, and of 23 fathoms in another, the great metalliferous mass was quarried for its entire width. At these respective levels, however, "not only had the body of ore diminished, but it

was of lower quality, whilst the expense of raising it had increased inversely in the same proportion. *Quarrying* was, therefore, discontinued, and mining operations were commenced on the richest of the tributary or subordinate parts—the Black Rock (bed) lode;" which, by aid of a steam-engine set up at the bottom of the great open cast, is still *mincd* some 65 fathoms below the surface. The North Discovery lode is worked to a depth of about 112 fathoms (Fig. 81).

The following description of the Parys and Mona mines was communicated to Mr. Pennant by Mr. Paul Panton of *Plás Gwyn*, Mr. Price's agent. The description is so good for the date to which it especially refers (1806) that nearly the whole of it is transferred to this volume.

"The Parys mountain copper vein is very extensive, and contains ore in bellies of various magnitudes. Such bellies, or bunches, are commonly called stock-works. The excavations in the mine are in extent agreeable to the quantities of ore they contained. But it must be observed that these vacancies were not entirely filled with copper ore, but partially with mineral stone, or matrix of the vein, mixed with ore and dead ground, which was requisite to be cut to give room to pursue the ramifications of the vein. This vein has been worked on a very large scale, upwards of 700 yards, besides considerable workings to the east and west of this length of ground. This length includes the Parys and Mona mines, which are both in the same ground vein. From the boundary of the two mines to the west end of the Parys mine is an open-cast excavation 200 yards long, 150 yards broad, and from 20 to 40 yards deep, which gives a content of 900,000 yards of removed natural ground. From the boundary of the two mines to the east end of the principal workings in the Mona mine is a length of vein of 500 yards, in which extent there are three large open-cast excavations, out of which full 408,000 cubic yards of natural ground have been taken. Some of the subterranean excavations in this part of the mine are very grand. One of them is 50 yards long, 30 yards wide, and 40 yards high from the bottom to the rugged corner of the arch, supported only by one pillar in that cavity. In another part of the mine is an excavation 40 yards in length, 15 in width, and 40 yards in one outer arch. The underground workings are too numerous to particularise. The whole of them will amount to a vacuity of 200,000 yards cubical measurement, besides shafts, levels, &c. Some idea may be formed of the vast bodies of ore this part of the mine contained by the quantity of ore raised by two bargains in three months in the year 1787: in the first, 2,931 tons of good copper ore, and only 92 tons of waste; in the other, 488 tons of copper ore, and 267 tons of waste, besides the ore raised by sundry other small bargains."

1806.	Men employed	227
,,	Gunpowder used	17,036 lbs.
,,	Candles consumed	26,283 ,,
1807.	Men employed	237
,,	Gunpowder used	15,345 lbs.
,,	Candles consumed	23,321 ,,
1808.	Men employed	122
,,	Gunpowder used	6,300 lbs.
,,	Candles consumed	9,200 ,,

The agent then describes the character of the ores raised and the mode

of dressing. The description of arrangement for dressing ores will form the subject of a separate section, as it applies equally to the processes adopted to remove the valueless matter from the richer metallic portion of several ores.

The Parys and Mona mines drain the surface so thoroughly, that for want of fresh condensing water, four of their five steam-engines are of high pressure. The Parys mine emits annually about 700,000,000 gallons of water

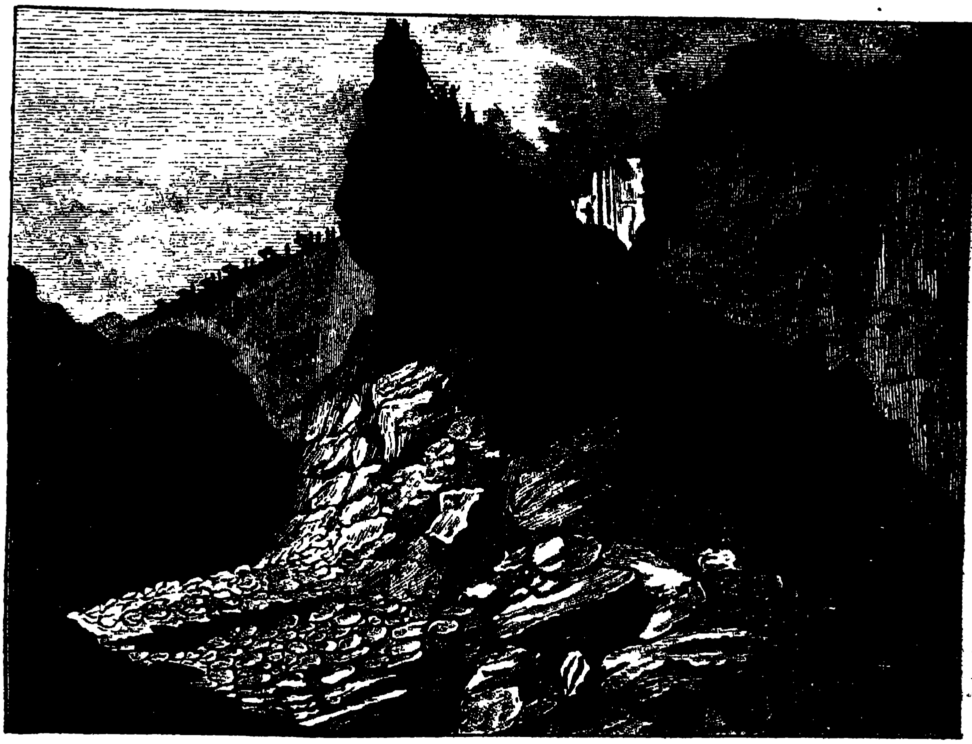


Fig. 82.—Great Open Cast in Mona Mine.

impregnated with copper. The average product of copper from this is from 55 to 60 tons, and the iron consumed in obtaining it is 600 tons. The copper found in these waters, as indicated from the precipitate obtained, varies from 4 to 30 per cent., according to the wetness of the season. A sample procured in the dry season was consequently rich in copper; its specific gravity was 1·055 at 60° Fah. The solid contents of one gallon weighed 4,960 grains, which gave peroxide of iron 1,680 grains, oxide of copper 80 grains, sulphuric acid 3,040 grains, muriatic acid 38 grains, and 122 grains of earthy matters which were not examined. In order to ascertain whether the copper might be extracted more cheaply by means of the galvanic current, or by the electrotype process, than by the ordinary means of precipitation, a piece of iron wrapped in a strip of brown paper was attached to a piece of copper, and both were immersed in a solution of copper ore in the muriatic acid to be examined. The first action which took place, however, was the complete reduction of the persalt of iron to the state of protosalt, at the expense of

the copper pole; after which the electric current began to effect its object, the copper being deposited, but from the copper which had been dissolved having also to be precipitated, the consumption of iron was 658 grains, whilst the actual increase in weight of the copper pole was only 64 grains, the quantity of copper originally held in solution. Different arrangements of batteries were tried, platinum, silver and lead were also substituted for the copper, but in no case was a deposit obtained from the water until the iron was first brought into a state of protosalt; when this was effected the result was 63 grains of copper obtained and 53 grains of iron lost.

Both zinc and iron, when put into the persalt of iron, first reduce the persalt to the protosalt, which fully accounts for the great consumption of iron for the small proportion of copper obtained from these waste waters of mines, and not, as was generally supposed, from the existence of free acid. The copper is never all precipitated from the water so long as persalt of iron exists in the solution.

The accompanying section (Fig. 83) gives the positions of the Black Rock lode, the vast Clay Shaft lode, and Carreg-y-doll lode, the two first

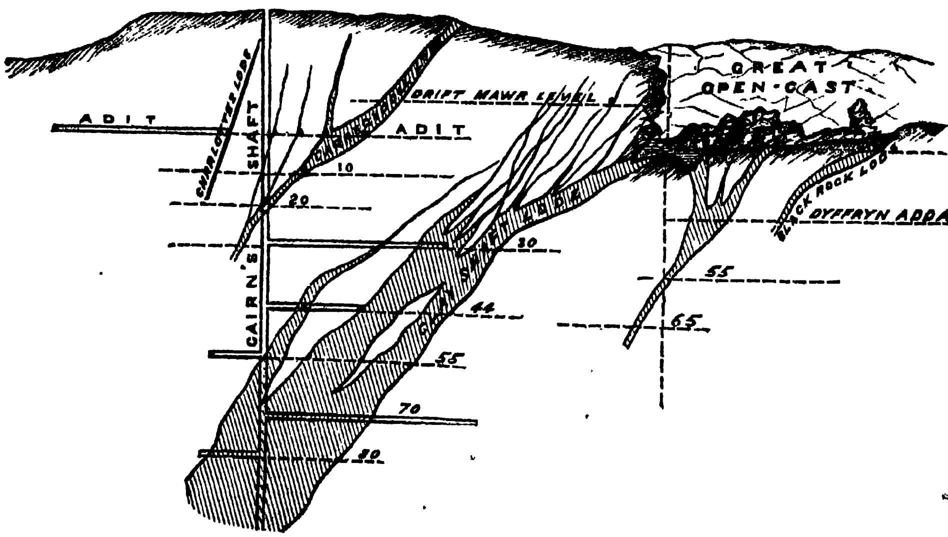


Fig. 83.—Section in Mona Mine.

being in immediate connection with the "great open cast." The conditions exhibited in this section are exceedingly remarkable. It is not easy to frame any hypothesis which will clearly explain the phenomena under consideration.

The most probable solution of the difficulties will be arrived at by supposing that the numerous small veins branching from the Clay Shaft lode, with the other lodes coming to the surface, formed a system of fissures when the whole was beneath the waters of the ocean, or of a large lake. The waters under these conditions—probably highly charged with carbonic acid—would be constantly acting, upon what may now be called the trunk lode, and be constantly enlarging it. This kind of action is indicated by the space left between the 55 fathoms and 44 fathoms, and the still larger space extend-

ing from the 70-fathom level to the 10-fathom level. The lines representing the fissure veins will convey to the mind a series of similar spaces which have not been removed. The conditions which were found to prevail at the first excavation of the great open cast would appear to indicate that at one period there existed here a copper deposit, such as was found in the copper Turf mine of Merionethshire. The copper held in solution, derived no doubt from neighbouring rocks, which were full of copper pyrites, as small strings, or actually disseminated through the rocks, would slowly find its way into the small cracks, and flow into the larger portions of the lode, gradually parting with its copper, generally in the form of a sulphide, and at the same time iron pyrites would be formed and precipitated. If we suppose the open casts in these mines to represent just such conditions as prevailed in the copper Turf mine of Merionethshire, it will not be difficult to understand the formation of the lodes, from which they are still deriving considerable profit. With a view to rendering this hypothesis clear, a description of the Turf mine will follow on a future page.

The returns since 1871 from these mines have been reported as follows:—

PARYS MINE.

	Copper Ore.			Fine Copper.			Precipitate.			Fine Copper.			Blue Stone.		
	Tons.	cwts.	qrs.	Tons.	cwts.	qrs.	Tons.	cwts.	qrs.	Tons.	cwts.	qrs.	Tons.	cwts.	qrs.
1871.	2,507	18	0	163	0	0	167	17	2	15	2	0		—	
1872.	2,813	0	0	182	0	0	155	0	0	13	19	0		—	
1873.	1,938	0	1	125	19	1	120	12	3	10	16	0		—	
1874.	3,343	9	2	62	10	0	119	19	3	10	15	0		—	
1875.	2,704	4	3		—		205	17	2		—		150	0	0
1876.	2,323	3	1		—		187	0	0		—			—	
1877.	2,154	10	0	42	15	0	150	0	0	19	12	2		—	
1878.	320	2	0	6	7	0	150	15	0	19	13	0		—	
1879.	180	0	0	4	10	0	100	4	0	12	13	0		—	
1880.	960	3	0		—			—			—			—	
1881.	863	7	0	34	10	0	119	5	3		—			—	

MONA MINE.

	Copper Ore.			Fine Copper.			Blue Stone.			Precipitate.		
	Tons.	cwts.	qrs.	Tons.	cwts.	qrs.	Tons.	cwts.	qrs.	Tons.	cwts.	qrs.
1871.	3,000	0	0	195	0	0	200	0	0	50	0	0
1872.	2,400	0	0	156	0	0	984	0	0	24	12	0
1873.	1,628	0	0	105	16	0	414	0	0	287	0	0
1874.	150	0	0	9	15	0	1,008	0	0	282	0	0
1875.	600	0	0		—		500	0	0		—	
1876.	800	0	0		—		50	0	0	332	0	0
1877.	1,040	0	0	38	0	0		—		270	0	0
1878.	1,022	1	0	37	6	0	360	0	0	302	16	0
1879.	766	15	0	27	10	0	548	10	0	202	0	0
1880.	2,019	0	0		—		1,569	0	0	166	0	0
1881.	3,804	0	0	152	5	0	1,460	10	0	409	0	0

Blue Stone.—A curious ore is found in Anglesea, called by the Welsh miners *Carreglas*, or blue stone. It lies generally on the top of nearly all the great bunches of copper ore, close to the surface of the ground, having been acted upon by the atmospheric changes of our variable climate during the course of years. The sulphides of copper and zinc are in many places carried off in solution by rain water, leaving the sulphide of lead, which is insoluble in water, behind, in a layer to the depth of two or three feet from the surface, having the appearance of a dull grey clay. Of this clay-lead ore large quantities were sold by the proprietors of Parys mine about the year

1786, and of the silver extracts from it, there were some pocket-piece coins struck off, in imitation of Parys mine, Druid-head copper pence then coined.

Mr. Samuel Lucas, of Sheffield, purchased several cargoes of it, which he conveyed round by sea, from Amlwch to Hull, and thence to Sheffield, where he smelted it for the silver it contained. There were two samples of the Parys mine clay-lead ore in 1824, tested with great care by a silver refiner, one of which produced 65 ozs. of silver in 20 cwts. of lead, or 1·548, and the other 56 ozs. in 20 cwts. of lead, equal to 1·640.

The "blue stone" of Anglesea contains sulphides of copper, zinc, and silver lead. A variety which occurs in Wicklow, Ireland, is stated to be a compound in equal parts of the sulphides of zinc and lead, containing silver.

The Turf Copper Mine of Merionethshire.—Sir A. C. Ramsay, in his "Geology of North Wales," describes the conditions under which the Turf copper mine was probably formed. Looking with the eye of a geologist, the quotation given at page 121 is of considerable value. The following abstract, from a paper by Mr. W. J. Henwood, gives the miner's ideas on the same remarkable cupriferous turf*:—

"The district to which Mr. Henwood's labours were directed a few years ago is the wild and romantic one—well known to tourists—about three or four miles north-west of Dolgelly, on the way to Trawsfynydd, and occupies the irregular triangle included between the rivers Mawddach and Babi. Although the surface is generally steep and rough there are some gentle declivities, and small vales so slightly inclined as to have permitted the formation of peat, and it is in these that the copper turf has been wrought.

"The copper ores which have been found in some abundance amongst the mountains of Merionethshire have not occurred in such long and regular lodes as characterise many other metalliferous deposits, but are for the most part obtained from the network of irregular streams, which, chiefly composed of quartz and carbonate of lime in ever-varying proportions, and frequently mixed with epidote and other minerals, conform more or less to the natural joints of the hornblende, slate, or Greenstone.

"At Burnloch numerous short thin veins and isolated spots of copper pyrites occur in a small rocky eminence, and the water oozing and trickling from it enters a field long cultivated, but from its infertility called Cae Drwg ('the bad field'). The soil was examined and gave traces of copper.

"At Benehos there are small quantities of antimonial grey copper ore, of copper pyrites, and of the blue and green carbonates of copper. The earth which receives the drainage of the pits sunk in pursuit of these ores gave slight but unequivocal signs of copper. Copper pyrites occurs at Tyn-y-myndd, but not abundantly. Immediately below, at Maes-y-Glwysan, the vegetable mould is about 3 feet in thickness, and reposes on a bed of rotten wood (hazel?) and decayed roots of grass of six inches deep. No sign of copper was detected in either of them; but a bed of peat beneath afforded a

* "On the Copper Turf of Merionethshire." By William Jory Henwood. ("Report of the Royal Institution of Cornwall.")

moderate produce of copper, and has been occasionally wrought. By far the best known and most extensive deposit of copper turf, however, is at Dolfrwynog, where some seventy acres of it were worked about forty years ago, at the base of a hill which forms the southern bank of the Mawddach, and receives the drainage as well of an extensive common as of a long level on a vein of quartz in which were found several irregular masses of copper pyrites weighing some tons each. The chief repository of the copper is a bed of peat of about 18 inches or 2 feet in thickness, which consists for the most part of dead grass mixed with great quantities of rotten wood (oak and hazel). Beneath the peat there is a bed of stones a few inches in thickness, evidently the débris of the neighbouring rocks. Many of the stones contain iron pyrites in abundance, and some of them are thinly incrusted with the green carbonate of copper. A second bed of peat underlies the fragmentary deposit, and also affords copper, but so scantily that it has not been wrought, and its thickness has not been ascertained.

"Some of the lower portions of the upper peat-bed were so rich in copper that they were carried to the Swansea smelting works in the condition in which they were extracted. Some of the leaves are said to have been covered with a thin pellicle of bright metallic copper; nuts were coated in like manner, and on being broken afforded also a kernel of the same; and I was informed that copper was in some cases deposited between the fibres of the wood, so that on being cut it exhibited alternate layers of vegetable matter and of metal.

"These were, however, exceptional cases. Ordinarily the turf was cut and dried by exposure to the air, and when sufficiently dried it was set in heaps and burnt. As the mass ignited, recently cut turf was added, which was soon dried by the heat; but especial care was taken that the burning heap should not burn into flame, for it then fused into a slag, which would not suit the purposes of the smelter. All the utensils employed, excepting only those for cutting the turf, were of copper, as it was found that iron ores were rapidly destroyed.

"After the fire had been continued for eight or ten days without intermission the ashes were fit for the furnace, and they were then sold to the Swansea manufacturers. In one year 2,000 tons of ashes had been sold, and had realised a profit of about £20,000. At the time of Mr. Henwood's visit there still remained an enormous quantity of copper turf, but as its ashes would not yield more than about 2½ per cent. of copper it was thought too poor to be wrought to advantage.

"Persons conversant with the copper turbaries consider the presence of metal in the soil indicated by the growth of the sea-pink or thrift, *Statice armeria*, which appears to flourish there with remarkable luxuriance."

Great Ormes Head.—There are some peculiarities in the deposition of copper in the beds of this headland which appear to prove that the deposition of copper ore is dependent on the nature of the rock. The beds in some places have a crystalline character, which appears to have a very close relation to the productiveness of the copper-bearing veins. Except when enclosed in a *crystalline* rock the veins are scarcely seen to exist, and are

never productive. The beds *a a* are the crystalline beds in which the veins *c c c* are full of copper ore, whereas in passing through the bed *b b* they fail entirely in the production of ore.

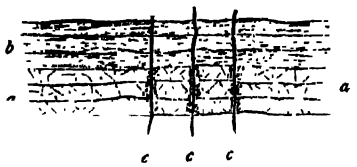


Fig. 84.

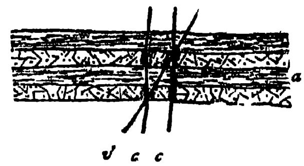


Fig. 85.

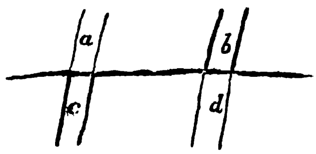


Fig. 86.

The beds are shown, in Fig. 84, alternating, the deposit of copper in the beds *a a* being a constant result. Another effect is illustrated in Fig. 85. The leading veins *c c* are sometimes interrupted by cross veins *v*. These cross veins are often favourable to the production of copper in the intersections, especially where it occurs in a favourable bed. The ore is then found to extend through the whole group, constituting a large deposit of copper pyrites, through all the beds.

Fig. 86, Copper ore is found at *c* and *b*, but none at *a d*. Yet there is no heave, the lines *a d* indicating the continuation of the lode in its non-productive state.

At the foot of Great Ormes Head, very near Llandudno, a copper mine was worked by a Liverpool merchant. He was quietly pocketing a few hundreds each year, as the profit of his copper mine, when quite unexpectedly it was found full of sea water, the ocean waters having found their way in through some fissures in the rocks. The fissures were eagerly sought for, and every one found was filled with cement; but they were never fortunate in finding the fissure through which the water entered the mine, and consequently the Llandudno copper mine was abandoned.

Alston Moor Mines, and others in the Northern Counties.—Although some attention has been given to the geological phenomena of the mining districts of the North of England, and the character of the mineral lodes, as far as the probable modes of formation are concerned has been noticed, it now becomes important to direct attention to the more characteristic phenomena which have presented themselves in connection with the opening of the mines.

The contents of mineral veins in Alston are generally—

1. Rider or *veinstone* or *dowk*.
2. Calcareous spar.
3. Cawk spar, heavy spar, or barytes.
4. Quartz spar.
5. Druse (a hard concreted stony crust).

Then white mineral soil, which is frequently lead ore; red fatty clay, indicating the presence of iron; bluish mineral soils; yellowish, ash-

coloured, and marbled soft soils, called *mother* by the Scotch miners; black and brown mineral soil.* The most promising of the soft mineral soils is of a brown colour, and of a lax and friable texture. This, arising no doubt from decomposition, is a variety of a *gossan* as it is called. The *Riders* of some *strong* veins are so hard as to resist the action of atmospheric causes. The great vein at Nun-stones, near Tynehead, is conspicuous as a pile of rocky ground at a considerable distance. The Nun-stones great copper vein (denominated in a lease, as Mr. Sopwith tells us, "*the back bone of the earth*") is the largest and strongest vein in Alston Moor. Where it passes Cross-gill Burn it is no less than 300 feet in width, and it throws up the strata 80 feet. Mr. John Taylor supposed this vein to be rather a collection of branches than one single continuous vein. He thought copper might be obtained in payable quantity in depth,—especially where it intersects Stow-crag vein,—where a rich but not large deposit of copper was found.

Regular ribs of ore occur in wide veins, running parallel to the rib and the rider. A rider in a vein is not, in the Alston Moor mines, always found in a continuous rib. Irregular masses of rider, and of ore, are found of all dimensions, "from the size of a fist up to the size of a hogshead, and much bigger" (*Williams*).

The working of the Alston Moor mines in olden time was exceeding primitive. Rude shafts were sunk into the vein, and when required, levels were driven into the hill to drain off the water. The lead ore was taken through the *drifts* (levels) by boys, and drawn up the shaft in *kibbles* or small tubs by a *whimsey* or roller worked by men or horses. Men or boys, according to the extent of the mines, drew the ore up the *sumps* (shafts underground connecting the levels with each other) which are formed from the deep workings. The levels were small, just sufficient to admit the workmen. They were rarely more than 4 or 5 feet in height, about 2 feet wide at the top, and from 15 to 16 inches only at the bottom. Though called levels, these ways or galleries were often much inclined; sometimes the ascent was as much as 45°.

At the commencement of the present century a spirit of enterprise led to considerable progress and improvement in the mines of Alston Moor. A writer at this time says: "The mines in Alston and Allendale are conducted on the most scientific principles, and the agents are men of skill, and well versed in mechanics."†

The discovery of Hudgill Burn mine caused great excitement, and led to the formation of several companies of mine adventurers.

The Flow Edge Mining Company commenced a trial of Middle Fell mountain. They drove a level 250 fathoms, and found only two small veins. They sunk two shafts from the surface, and a sump to the four-fathom Limestone. They also drove a level to the north, and having discovered a vein made a rise to the middle of the Great Limestone, which vein they explored for 20 fathoms, finding only a few samples of ore. This company lost about £2,000. They abandoned the workings, and the mine was unworked for eight years. In 1812 Messrs. John and Jacob Walton obtained leave to

* Williams, "Natural History of the Mineral Kingdom."
† Mawe, "Mineralogy of Derbyshire."

make a new trial. Four men were employed to drive 20 fathoms of level at £4 4s. per fathom, by which they made 16s. a week. This continued for nearly two years, the average of the bargains being about £3 10s. per fathom. In this time they drove 70 fathoms.

In April, 1814, a vein was discovered of good appearance, but so situated that it would not pay for working. They drove through this vein, which was 2 feet wide. A *rise* (*i.e.* a working upwards into the strata) was made to the Great Limestone, and the vein was found nearly filled with carbonate of lead, or white lead ore. Four miners took a bargain to work the vein at 18s. per bing (of 8 cwts. each), until midsummer (nine weeks). By that time they had raised 800 bings, and cleared £80 per man. The workings were now continued at wages of nearly £10 per week. The veins of Hardgill Burn have since produced ore from 10 to 12 feet wide, and in some places the width increased to 20 feet. The company spent about £360 before they reached the vein, and altogether about £2,300. Its produce in 1820 was 9,000 bings of ore. In 1829 the horse levels in it were more than four miles in length, and the value of the silver produced in 1821 was £8,400. The profits of this mine for many years appear to have averaged £30,000 per annum.

In 1812 the Commissioners of Greenwich Hospital agreed to purchase the ore from such mine adventurers as had no smelting establishment, and they were thus rendered independent of the fluctuations of the market.

In 1817 Langley Mills were erected chiefly for the purpose of smelting the ores of zinc. These for a few years were successful, but the price falling from £70 to £40 per ton, the concern was abandoned, and for some time zinc was imported from Germany, at less price than the English smelter could produce it.

There is a fact connected with the lodes of Alston Moor which must not be neglected. In the North of England generally, the north and south veins divide those running east and west, in almost every instance. The exceptions are very few. The divided vein, if it *hades*, and the vertical throw of the cross vein be considerable, will be displaced, so that its divided parts remain parallel, but on coincident planes, and viewed in a horizontal section *appear* to have suffered a *lateral movement.* Of the *pipe veins* a description has been already given. Williams gives numerous examples of pipe veins, and of *streek*, *flat*, or *dilated* veins. He denies that any of these are fissure-veins. He says: "In fact they are no fissures, but a space or opening between two strata, or beds of stone, the one of which lies above, and the other below this vein, in like manner as the roof and pavement of a stratum of coal are above and below that coal. When the strata between which this vein is found lie nearly parallel to the horizon, the vein is likewise in the same horizontal position; and when the strata vary from the horizontal position, the dilated vein varies likewise with the same degree of declivity, and this of necessary consequence, as the vein does not burst the strata, but always continues between the same two beds of stone. Some English miners call the flat veins *streeks*, and when they have both a rake vein, and one of these in the same field, they distinguish them by the appellation of *the vein* and

the *streek*. By the word *streek* they mean stretch, or a vein between the strata which stretches or spreads in a horizontal position." *

The following is abstracted from a list of the lead mines "which are, or have been worked in the manor of Alston, in the county of Cumberland, belonging to the Commissioners and Governors of Greenwich Hospital, including the mines at Cross Fell and Tyne Head, together with an account of the mineral substances they produce," by Westgarth Forster. †

Alston Moor	69 mines	Lead.
"	3 "	Copper (Back-bone, Corn-riggs, East-burn).
Allendale	7	Lead.
Derwent	3	Lead.
Weardale	36	Lead.—Belongs to the Bishop of Durham, formerly principally occupied by Colonel and Mrs. Beaumont.
Teesdale	38	The property of the Earl of Darlington.
Westmoreland	12	The property of the Earl of Thanet.

In relation to the Alston Moor district, and indeed to all the mining tracts of the northern counties, there exists a peculiarity which does not admit of easy explanation. Is there any distinctive difference in the metalliferous characters of the Upper and the Lower Limestones? We know that one is highly metalliferous, and the other rarely so. Mr. Wallace, looking at the geological conditions, with especial reference to his own views, relating to the *laws of hydrous agency*, remarks: "In Alston Moor the position of the series of beds called the *lower strata* is more varied than the group forming the *upper strata*. In some places they are considerably elevated above the bottom of the valleys, or even *basset* at the summit of the mountains; in others they lie buried at great depths, the whole of the upper portion of the Mountain Limestone, and part of the Millstone Grit, reposing upon them. In the former case, the conditions for promoting the percolation and circulation of fluids in the veins vary in a manner similar to those connected with the veins in the upper strata. In the latter, because of their being so far removed from the surface, very little variation can occur. The subject may therefore be viewed under two aspects: the conditions connected with the deposition of lead ore in the veins near the surface, and those connected with its deposition at great depths below." Remembering that the same veins which have produced enormous quantities of lead ore in the *upper strata* are very poor in the lower, and also bearing in mind that the condition of mineralization in each case must be similar, it is difficult to arrive at any other conclusion than that the variation arises from some difference in the ages of the two sets of rocks, the lower stratum being, of course, older than the upper stratum. The evidence we have appears to favour the idea, that the period of mineralization was after the formation of the upper beds, and that they acted as filtering media for all the fluids collected from the surface of the country or from the upper rocks, the water being deprived of all, or nearly all, its metallic salts by passing through them, thus forming the more productive lead veins. It must be borne in mind that the same fissures which have

* "The Natural History of the Mineral Kingdom," vol. i. p. 339. By John Williams. 1789.

† "A Treatise on a Section of the Strata from Newcastle-upon-Tyne to the Mountain of Cross Fell, Cumberland, with Remarks on Mineral Veins in General; also Tables of the Strata in Yorkshire and Derbyshire." Second edition, greatly enlarged. By Westgarth Forster. 1821. A third edition has been published recently.

become rich in lead ore in the upper parts, are poor in the lower, the conditions for mineralization being very similar in each. The difference between them must arise from a greater portion of ore-producing matter entering, in probably a fluid state, into the fissures of the upper bed, than can flow through the lower part of the same fissure." Mr. Wallace, whose views in general are not exactly those usually entertained, gives a good example. He says: "To particularise one case, the Browngill veins, on the west side of the outcropping of the Great Limestone, are connected with conditions very favourable for promoting the percolation and circulation of fluids. Had these veins traversed the upper series of strata, and the Great Limestone occupied the position of the Scar Limestone, there can be no doubt whatever but that they would have contained very rich deposits of lead ore instead of the few poor ones, which, with one or two exceptions, have not repaid the cost of extraction." The following table represents the position of the Great Limestone bed relative to the Scar Limestone and the Whinstone-Sill.

		Ft.	in.
a.	*Ten small beds of hazle*	—	
1.	Fell top Limestone	4	6
b.	*Nine beds of hazle, ironstone, &c.*	—	
2.	Little Limestone	6	0
c.	*Five beds of coal sill*	—	
3.	GREAT LIMESTONE	63	0
d.	*Two beds tuft and hazle*	—	
4.	Four fathoms Limestone	24	0
e.	*Natrass gill hazle*	—	
5.	Three yards Limestone	9	0
f.	*Six fathoms hazle*	—	
6.	Five yards Limestone	15	0
g.	*Slaty hazle*	—	
7.	Upper SCAR LIMESTONE	30	0
h.	*Alternating beds copper, hazle, &c.*	—	
8.	TYNE-BOTTOM LIMESTONE	24	0
i.	*Whetstone Bed*	—	
j.	WHINSTONE-SILL (120 feet)*	—	
k.	*Three Beds of hazle*	—	
9.	Jew Limestone†	24	0
l.	*Slate*	—	
10.	Little Limestone	18	0
m.	*Hazle*	—	
11.	Smiddy Limestone	31	6
n.	*Hazle*	—	
12.	Limestone	25	6
o.	*Hazle*	—	
13.	Robinson's lime	21	0
p.	*Hazle*	—	
14.	Melmerby SCAR LIMESTONE	132	0
q.	*Several beds of freestone and coal, with two thin beds of Limestone, to the total thickness of the whole of the strata of* 1,133 *of Sandstone,* 1,181 *of plate,*‡ 480 *of Limestone.*		

Referring to the section of the strata which has been given, it becomes interesting to learn the real condition of the beds (especially of the Limestone beds) in their metal-bearing characters. Nearly all the mines are found to be productive in the upper beds only. This condition indicates, that the lead-producing cause, whatever it may have been, was not established when the deeper beds were in process of deposition. The character of the deeper mines is given below. For these particulars we are indebted to Mr. Adam Walton, the Moormaster of Alston.

"At Rodderup Fell the miners have reached the 'Jew Limestone,' which they have found to be comparatively worthless—unless at Smittergill—where but little has been done successfully. Rodderup Fell is the only mine in this county in which the 'Jew Limestone' has been worked, or which has been reached.

* The Great Whin-Sill is a basaltic Greenstone, similar to that which occurs at Salisbury Crags and at the Giant's Causeway. Mr. Winch ("Geological Transactions," vol. iv. p. 79) says the Great Whin-Sill of the lead-mine district does not consist of the whin of the colliery sinkers, but is really basalt, coarse-grained in texture, and composed of white felspar and black hornblende.

† The Jew Limestone. At Hilton lead mine this stratum is close to the bottom of the Great Whin-Sill, and is nearly eighteen fathoms in thickness.

‡ Below the lowest plate bed we find six fathoms of freestone, a bed of Limestone, the lowest calcareous stratum of the section; below this the Red Sandstone occurs in irregular beds.

"The 'Tynebottom Limestone,' next above the 'Jew,' has been worked at the following mines:—

Metal Band (worthless)	In Colonel Byng's Tynehead Manor.
Tees Side (moderate)	
Providence (poor)	
Lady Vein (poor)	
Dosey (fair)	
Tyne Green (fair)	
Pattersyke (poor)	
Stow Craig (lead and copper moderate)	
Ashgill Field (poor)	In London Lead Company's Priorsdale Manor.
Tyne Bottom (fair)	In G. Hospital's Manor."
Windshaw Bridge (rich)	

They are working in a Limestone at present, at the "Green Hurth" mine in the Duke of Cleveland's manor, which they suppose to be Tynebottom Limestone; the results are uncertain. The value of the lead mines in Alston Moor in the last century, as obtainable from the moormaster's book, was as follows in the three years given:—

	£	s.	d.
In the year 1766, 18,600 bings (8 cwts.), worth on an average £2 15s. per bing	61,950	0	0
„ 1767, 24,500 „	77,162	10	0
„ 1768, 18,730 „	62,213	10	0

To the general poverty of the veins in the Lower Limestone of Alston Moor, Rodderup Fell presents a remarkable exception, large quantities of lead ores having been produced since the mine was first opened in 1831.

A prejudice,—if it can truly be so called,—exists amongst the miners of this district against the Lower Limestone strata producing lead ore. A few trials have been made by sinking into this Limestone, but they have rarely been productive of any favourable result. Mr. Wallace says: "Between Calvert and Rodderup Fell veins, the east and west veins have contained scarcely any ore. Trials have been made to prove them in localities where the conditions for promoting a free percolation and circulation of fluids are as favourable as those connected with veins in the upper beds, which have contained rich deposits of lead ore; thus tending to support the hypothesis that the poor deposits of lead ore in the veins in the lower beds are due to the paucity of some *unknown lead-ore-producing substance* not entering so abundantly as a component part of the enclosing rocks."

The Rodderup Fell vein is supposed to be a combination of two veins called Craig-Green Middle and How Hill veins. It is wide and well-mineralised; it throws up the *north cheek* about 15 feet. The situation of this vein is considerably to the south of the steep banks of the Black Burn. The course of it is at a considerable distance from the summit of the hill, and the elevation of the surface is not very rapid. The strata in this locality have a very rapid inclination, and the dip must be nearly at right angles to the direction of the Great Sulphur vein; consequently, on the line of the Rodderup Fell vein the strata rise in a direction from the east to the west; the circulation longitudinally in the open spaces in the veins in hard strata must therefore have been to the east.

It will be seen by the small map (Fig. 87) of the Rodderup Fell veins that the strata have been much fractured by intersecting leads and veins.

The parts of the main lode which are indicated by a darker line are the productive sections of the mine.

The whole of the east and west veins, which traverse Middle Fell, and cross the vale of the Nent between Long Cleugh and Gallygill Syke veins inclusive, fall into those portions of Rodderup Fell vein containing the richest deposits of lead ore. No doubt the numerous small *leads*—channels —well marked in the map, which represent respectively the *Dryburn Washpool* veins, *Dryburn vein*, and *Dryburn Peak Fell vein*, have been the courses in which fluids have been collected, and conveyed to Rodderup Fell vein.

It is a curious fact, noticed by Mr. Wallace, that all the fluids, after flowing in the *leads* in a north-western direction, should be forced to flow in an opposite way, or nearly east. Rodderup Fell vein is intersected by two

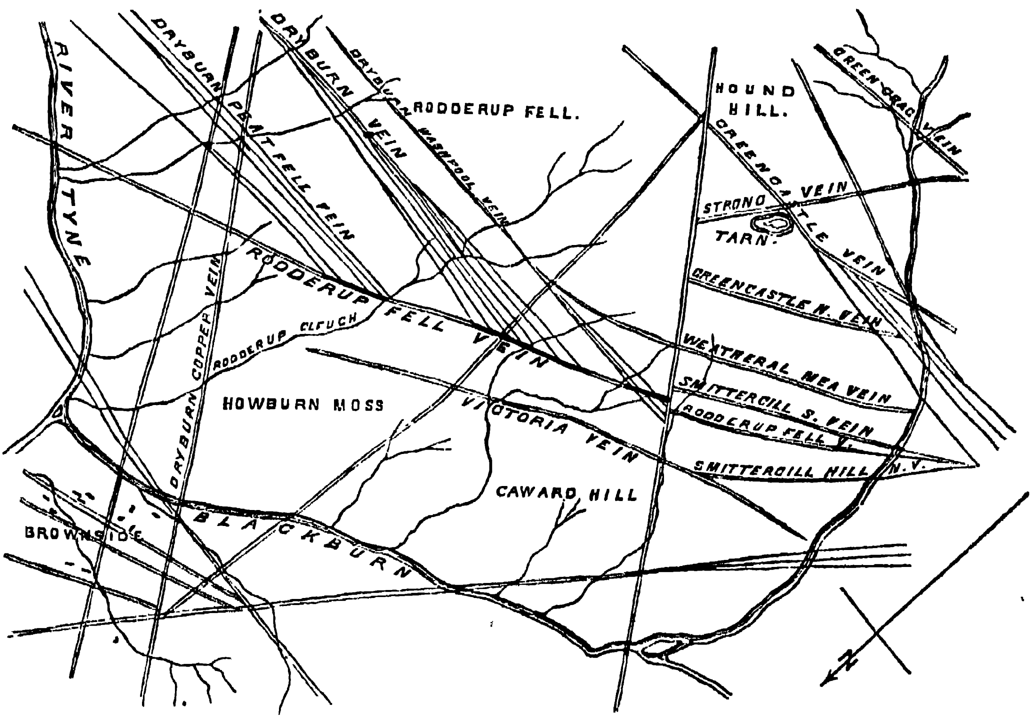


Fig. 87.—Rodderup Fell Mine.

cross veins, which throw up the west cheek, and many think it is due to this that it has contained very rich deposits of lead ore in the strata elevated by the throw of these cross veins.

A close examination of the map of a portion of Rodderup will show that the richest portions of the veins (indicated by blacker lines) are where there have been lateral feeders. The fluids flowing through the smaller fissures appear to have taken up metalliferous matter from the rocks, which has been again deposited, to form larger masses in the main lode, where there was some disturbance produced by the flowing in of the smaller streams.

The conditions prevailing at *Smittergill Head* mine appeared to be similar to those prevailing at Rodderup Fell. An industrious and expensive

search was carried on for some years, but as the result was not equal to the expectations, the mine was eventually abandoned.

Dufton Lead Mines, Westmoreland.—Dufton is situated near what was formerly the great coach road from London to Glasgow. The Dufton mine lies 3 miles north of Appleby, on the west of a range of hills which extends from the borders of Scotland, and includes Cross Fell and the mining district of Alston Moor. The following account is obtained from a paper published by Professor T. Allan, of Edinburgh.* After describing the peculiarities of the country around Dufton Pike, which is entirely composed of Red Sandstone covered with alluvial soil, Mr. Allan says: "The ravine in which the mines are wrought may be about half a mile wide at the entrance, and extends from Dufton Pike about a mile and half. . . . . I observed Slate rock sufficient to mark the existence of the transition series, and on it rested strata of Limestone and what is denominated in the country *hazle-sill*, which I found to be a thick bed of pale-coloured Sandstone."

In the beginning the vein was wrought on the summit of the western front of the precipice, and the lead procured by *hushing* (that is, by bringing a stream of water to run over the place where it cropped out). A level was subsequently driven through the very solid Greenstone—known as *whin-sill*—which was constructed with great judgment. The mine was well ventilated and very free from water. The Greenstone is, at Dufton, at least 20 fathoms thick, but in Teesdale it extends to 60 fathoms. It is here interposed between two beds of Limestone, the upper bed being 4 fathoms thick and the under bed only 3 yards. The lead is worked in both of these Limestone beds, and is thus described by Mr. Allan:—

"The vein passes through all the three beds, but is prolific in lead only in those of Limestone. There it widens out into plates, filled with spars and metal; but in the Greenstone it is compact and narrow, still, however, producing a small particle of lead now and then, as if to identify the course. Beyond the range of these three beds the workings were not prosecuted, and I could not learn what appearances the vein at these extremities assumed. The nature of the strata, both above and below, appeared very unusual; over the 4-fathom Limestone a bed of *plate* (very friable shale) occurs, then a Sill of Hazle, with some small seams of coal; under the lower bed of Limestone another bed of Hazle and strata of coarse Limestone appeared; and these I believe to rest upon the transition rocks.

"At the extremity of the north side of the ravine there is a hill, connected at its base with that in which the ravine is. It is singular to observe how abruptly the metalliferous strata are cut off; these jut boldly out, and exhibit their regular horizontal position distinctly to view; while the hill, whose base touches upon that on which they rest, presents a rugged surface, composed of strata set upon edge."

It is remarkable to observe the lead lode—being rich in that mineral in the Limestone, and almost declining to nothing in the Greenstone.

The author visited these mines with Mr. Wallace in 1864, who then had the management for the Governor and Company of Lead Miners.

* "A Geological Account of the Lead Mine of Dufton, in Westmoreland." By T. Allan, &c. &c. ("Journal of Science and Art." Edited by W. T. Brande, F.R.S.)

Teesdale.—The water division between Alston Moor and the Dale of the river Tees is called *Heaven's Water division*,—a rivulet called Crookburn being the actual boundary between the counties of Cumberland and Durham, and the parishes of Alston and Middleton in Teesdale. As far back as the reign of Edward III., the Scottish army, then encamped in Weardale, made their escape from him, by laying boughs across Yadmoss, to prevent their sinking in the bog. It was not until 1824 that a passable road was made there, so long did this Dale remain in its primitive state. The principal veins run east and west, and the hade, or inclination of the vein, is north. As a rule the upper Plate shales, often reaching the surface, are most productive. In some cases the 12-fathom Limestone has yielded considerable quantities of ore, but the deposit in it is very irregular.

Generally the vein is wrought at so much per cubic fathom, and in other cases at so much per bing; the workman pays for drawing the ore, and if engaged at so much per bing, also for dressing, which amount is deducted from his yearly account.

The principal part of the ore is raised on the manor of the Duke of Cleveland, and a duty is charged of one-sixth. The Governor and Company had also ground leased of Mr. S. Hutchinson, J. Bowes, and of the Bishop of Durham, or, the Ecclesiastical Commissioners. The average percentage of lead in the ore is about 75, and the silver is generally about 10 ounces per fother of 21 cwts.

As a means of saving the lead from the smelting fumes, 1,400 yards of chimney are used, terminating in a shaft over 150 feet in height. During the passage of the smoke through the chimney, it was subjected to a process of filtration, by means of a bed of rubble stones, while self-acting buckets are suspended above, which are each supplied with water. When about three-quarters full they turn over, emptying their contents on the stone bed, washing off the lead which has collected.

Forster, in his "Section of the Strata," enumerates thirty-eight mines in Teesdale, all of which, with a very few exceptions, were in the occupation of the London Lead Company. The mines at Manor Gill and Lodge Syke, near Middleton, have been immensely rich. The London Lead Company's smelting works were erected about half a century since by the London Lead Company, under the immediate direction of their manager, Mr. Stagg. The importance of the Governor and Company in the history of mining, especially their early experiments on smelting lead ores with coal, demands some especial notice.

In the early part of the reign of William and Mary (1688-94), a lady —a member of the Society of Friends—witnessing the destitution amongst the working classes, especially in the north of England, was induced to bring the matter before one of the annual meetings of that body. This lady suggested the formation of a company, which would not only confer—by employing them—a great boon on the destitute part of the population, but secure a satisfactory return for the capital expended. This led to further investigations, which resulted in the formation of a chartered company under the title of The Governor and Company of Lead Miners. For the first century, although a considerable amount of lead was raised, and

great improvements were made in the smelting operations, the expectations of the projectors do not appear to have been realised. About 1750 the company were employing only eight men in their underground operations, and they contemplated employing their capital in some more promising speculation than lead-mining. Lodge Syke was one of some plots of ground in Teesdale leased to four local speculators, who, after making a number of surface trials by *hushing*, allowed their lease to expire, under the impression that there was no prospect of reasonable remuneration. The Governor and Company took this sett, but with no very satisfactory result. They called in two agents to examine and advise them. One of these proposed to entirely suspend operations, pronouncing Teesdale to be so unproductive that he considered it foolish to attempt to develop its mineral resources. The other advised the workmen to try a *hush* on another part of the ground, the result being the discovery of a vein richly charged with ore, close to the surface. This gave a new impetus to labour, and those who were able and willing found remunerative employment. Mr. R. Stagg, who was made superintendent of the works, erected a crushing-mill. He made new arrangements for working the sieves used for jigging or hutching the *bouse* or rougher part of the work, and he introduced the German swing buddle. The mines were wrought from that time, not only with an eye to the profits of the masters, but also to the safety of the miners. The overmen were selected from the most intelligent, sober, and industrious workmen. A commodious school was erected, and cottages were built, and, at a low rental, were allotted to the most deserving of the workmen. From that time the district of Teesdale has been a productive one, producing, in 1881, 5,090 tons 15 cwts. of lead ore. The Alston Moor mines, especially at Nenthead, in Cumberland, were also in their hands, and in addition to Silverband in Teesdale, they worked Cornish Hush, Whitfield Brow, and others at Bollyhope in Weardale.

The Governor and Company also possessed mines in Wales, and smelted ores on the Dee, at Bagillt. The letters L. C. (*London Company*) were still to be seen in the plaster of a smelting-mill at that place, a few years since.

They also held for some years the Great Laxey mine in the Isle of Man, the Lead Hills mines in Scotland, the Millfield mine in Derbyshire, and the Derwent and Stanhope Burn mines in Durham; and, so extensive were their operations, in addition, this Lead Company worked the Dufton and Hilton mines in Westmoreland, and Lunehead in Yorkshire.

It cannot but prove instructive to examine the state of the mines of the North of England, as they were in 1821, and to contrast them with those working at the present time. For the earlier date Westgarth Forster's "Section of the Strata," and other works, have yielded much information.

After leaving the coalfield, the first mine is Healyfield, which is a very ancient one. Forster says of it: "It has been worked for a great number of years, and still continues to produce lead, although in smaller quantities than formerly." In 1881 Healyfield produced 181 tons of lead ore, producing 2,170 ounces of silver, the value of the produce being £1,640. The next mining field is that of Shieldon, one mile west of Blanchland, in The workings were for some time in the hands of the

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London Lead Company, and they obtained much ore from the upper strata; but, until recently, these mines have not been successful.

The produce of the Derwent mines for the last eight years has been as follows:—

	Lead Ore.		Lead.		Silver.	Value of Ore.		
	Tons.	cwts.	Tons.	cwts.	Ounces.	£	s.	d.
1874.	312	7	231	2	2,048	5,198	2	2
1875.	401	5	281	16	2,445	5,943	1	3
1876.	328	3	227	13	1,548	4,745	2	10
1877.	409	16	275	8	3,850	5,533	2	9
1878.	418	0	292	12	4,038	4,420	7	0
1879.	385	0	289	0	4,335	4,050	7	6
1880.	469	17	281	15	1,412	5,483	0	7
1881.	325	0	195	5	975	3,268	11	10

In the above returns the lead ore from Jeffrey's rake, about two miles south-west of Shieldon, are included.

Contiguous to the *Derwent* mines are those of *Allenheads*, which have been in the Blacket family for a century and a half. The mines in *Weardale* have, for a considerable time, been in the hands of W. B. Beaumont, M.P., who has recently surrendered them to the Ecclesiastical Commissioners.

The produce from these mines for the last five years has been as follows:—

		Lead Ore.		Lead.	Silver.	Value of Ore.		
		Tons.	cwts.	Tons.	Ozs.	£	s.	d.
1877.	Allendale and Weardale	9,821	0	7,366	30,894	116,012	10	0
1878.	Allendale and Weardale	4,267	0	3,593	21,157	45,105	10	0
1879.	Allendale	584	8	1,218*	6,080	17,052	0	0
	Weardale	1,039	10					
1880.	Allendale	550	10	5,076*	27,669	37,145	0	0
	Weardale	3,359	14					
1881.	Allendale	447	18	2,454	16,968	36,120	0	0
	Weardale	2,825	4					

The mines in this district are mostly worked in soft strata, the veins commonly containing much soft fluor-spar. An old mine called *Brecon-side*, working in 1809, furnished for many years 10,000 bings per annum.

The remarkable dyke called Burtree Dyke, and its influence on mineral veins, must be particularly noticed. This is a cross vein of immense magnitude, and may be advantageously seen near Burtreeford in Weardale, and traced, crossing the Burhhope, a little above Wearshead. It may also be seen in Inshope and Langdon. The throw may be ascertained by observing that the Great Limestone forms the bed of the Inshope, on the east side of the dyke, and that on the west side, the same rock is found upon the top of the ridge, where the mountain track goes over it to Grass Hill. This upcast is at least 80 fathoms, the west side being elevated to that extent. The several beds of rock rise rapidly towards the dyke on each side, forming in some places an angle of 45° with the horizon. It is deserving of notice that the elevation, or depression of the strata, by veins is usually very limited in extent, for at a distance of half a mile from the strongest, the several beds are found to occupy the place which their general position and rise would assign them. Before leaving this subject we desire to give an estimate of the average produce of the mines in Teesdale, Weardale, Allendale and Alston

* Much of the ore raised in 1879 was not smelted until 1880.

Moor, including the mines at Cross Fell, along with some other mines in Westmoreland, from the year 1800 down to 1821. It is important to preserve every record we can obtain of our mineral produce.

	Bings per annum.
Teesdale mines, in the county of Durham	8,000
Weardale mines " "	17,000
Allendale mines, in Northumberland	8,000
Alston Moor and Cross Fell, in Cumberland	19,000
Dufton Fell, Dun Fell, and Hilton mines, in the county of Westmoreland	1,500
Total	53,500

The deposition of lead ore in the Allendale Mines is altogether remarkable. We find there rake veins, and flat or dilated veins putting on very varied characters, sometimes assuming the conditions of beds, or of the flat lodes, and *carbonas* of Cornwall. Frequently singularly rich cavities of lead ore have been found in the Great Limestone. All the conditions point to the action of water highly charged with carbonic acid, which has been, for long periods of time, acting by dissolving the lime and thus forming caverns; these subsequently being filled with lead ore, by a gradual deposition of it from fluids, bringing the metal in solution from the neighbouring rocks. Westgarth Forster informs us that some of these caverns have produced upwards of 400 tons of ore, most of it "being found in a loose state upon the soles of the cavities, which has probably fallen from the roof at some remote period of time." We may infer from this that, by the percolation of water through the Limestone, stalactitic masses of galena were formed, which eventually were broken off by their own weight, and deposited at the bottom of the caves. The *Great Burtree-ford* dyke has produced a great dislocation which has disturbed all the veins. Those veins have not been thoroughly proved, and therefore a new mining district may, in future years, be created by some bold and judicious adventurers.

The mining field of Allenheads has been very extensively worked by Mr. W. B. Beaumont, M.P., under the experienced scientific management of the late Mr. T. Sopwith, a gentleman who was well known for his excellent works on mining, and for his beautifully-constructed models of mines and mining districts, which may be studied in the Museum of Practical Geology with great advantage by all who contemplate embracing mining as a profession, or adventuring in mining explorations. Owing to the low price of lead, these mines have not been profitable for the last few years, and they have been recently abandoned, leaving a large population, drawn to the district by this important industry,—which has yielded a princely fortune to the lessee in past years,—in a state of considerable distress.

Swaledale Mines, Yorkshire.—There are a few points of interest which occur in the Swaledale district to which attention is required. The principal portion of the lead raised in Swaledale has been obtained from the Limestone beds. Some idea of the value of the production of lead ore from the mines of Swaledale may be formed from the following returns of four years when they were at their richest:—

In 1857, 5,537 tons of lead ore.	In 1859, 5,717 tons of lead ore.
" 1858, 6,576 "	" 1860, 4,878 "

The mines of Swaledale are as follows, and their present condition will be apparent by the returns of such as are productive:—

	1880.	1881.		1880.	1881.
Arkengarthdale	1,659	1,959	Hurst	55	—
Beldi Hill	—	—	Old Gang	650	294
Blakethwaite	—	—	Surrender	108	103
Ellerton Moor	—	—	Swinnerside	—	—
Fell End	2	3	West Swaledale	—	—
Grinton Moor	—	—	Whiteside	—	—

Distributed over an area of about 200 square miles, there are 192 distinct veins known in Swaledale, and of these 170 are returned as having produced lead. The miners of this district place great reliance on the character of the *rider* in a vein, as an indication of its probable productiveness.

The *rider* of the northern miner is any *mineral matter* existing between the sides or walls of a vein, the thickness of the rider being determined by the width of the vein. This rider is usually divided into *the fragmentary or primary rider*, and exists in three forms: the Limestone rider, the Chert rider, and the Grit rider; these names indicating that the veinstone has been derived from the rocks through which the vein passed, that it is indeed broken portions of the adjacent beds, cemented by the infiltration of water containing calcareous matter.

The Mines of Wicklow and Wexford, &c.—Mr. Thomas Weaver,* in his "Memoir" read before the Geological Society on the 15th May, 1818, deals especially with that portion of Ireland which is bounded on the east by the Irish Channel, on the south and west by the mountains which confine the Suir and the Shannon, and on the north by the hills of Louth, Meath, Cavan, and Longford, and by a line produced from thence to the Bay of Galway. In his examination of the Granite, Mr. Weaver says: "The minerals which I have incidentally observed disseminated in the Granite, or imbedded in the contemporaneous veins that traverse the rock, are schorl, tourmaline, garnet, beryl, rock crystal, epidote, heavy spar, *magnetic iron* ore, *galena*, *copper pyrites*, and *iron pyrites*." Dr. Taylor informed Mr. Weaver that he had discovered in the Granite *malachite*, *arsenical pyrites*, *tinstone*, spodumene, and a new mineral called killinite. The occurrence of the ores of lead and copper, in quantity, in the Granite is so rare that it deserves especial attention. This appears to militate against the hypothesis that "rock conditions" are important in regulating the deposit of ores. Mr. Weaver remarks on the discovery of tin: "It is an interesting fact, that this metal should at length have been discovered in the rock in this county, although found only on a contemporaneous vein traversing a loose block of Granite, for its existence in the county of Wicklow *in the form of stream tinstone* had been ascertained several years ago, by the operations of the directors of the works at Croghan Kinshela."

The eastern mountain chain of this district is remarkable for being very metalliferous, while the western side of the Granite region is equally remarkable for the total absence of metalliferous ores. The lead vein of Dalkey is situated near the north-eastern extremity of the eastern tract, and it

* "Memoir on the Geological Relation of the East of Ireland." By Thomas Weaver, M.R.I.A. ("Transactions of the Geological Society," vol. v. 1821.)

ranges *in the Granite* north-west and south-east, dipping 70° to the north-east. The outcrop of this vein is seen on the coast, from 4 to 5 feet wide. It is composed of disintegrated Granite, with quartz, in which some *green lead ore*—no doubt the result of chemical action—is seen; and, in the refuse of the mine, which is filled with sea water, galena, blende, and barytes are found.

At Ballycorus there are two veins ranging in the same direction, but one of those veins dips to the north-east and the other to the south-west. The veinstones are quartz and heavy spar, which bear lead ore in short bunches from a few inches to 1 and 2 feet in width, and varying in length from 1 to 3 feet, consisting of fine-grained galena, yielding 75 per cent. of metal, with carbonate of lead, blende, and pyrites.

To the west of Lough Dan is a vein traversing the Granite brow of Carriggeenduff, and ranging across the valley. This vein is from 3 to 4 feet wide, and dips 80° towards the east. A little galena is found in bunches, and disseminated, with occasionally a small quantity of copper ore.

Luganure vein runs wholly in Granite. Its course is about 1,000 fathoms in length, and it has been explored to the depth of more than 200 fathoms. It dips 65° towards the west. This vein has yielded in many parts from 3 to 4½ tons of galena to the fathom, either in layers parallel to the walls or in disseminated masses. Blende is not uncommon, and copper pyrites also existed.

The following is a statement of the production of Luganure for the twelve years ending 1881 *:—

	Lead Ore. Tons.	Lead. Tons.	Silver. Ozs.	Value of Ore. £
1870	1,336	1,002	—	—
1871	1,085	813	—	—
1872	925	701	—	—
1873	1,180	885	—	—
1874	1,749	1,311	6,555	20,988
1875	1,850	1,387	6,925	20,354
1876	1,825	1,368	6,840	20,077
1877	1,655	1,241	6,205	18,214
1878	1,526	1,150	5,650	12,208
1879	1,124	800	4,000	7,308
1880	897	672	3,360	10,147
1881	822	616	4,932	6,268

Glendalough vein ranges east and west. The line in which it may be traced is about half a mile, but to the west it probably ranges far up into the Granite of the interior, while to the eastward it does not seem to extend much into the mica Slate; not appearing, as might otherwise be expected, on the precipices on the Glenasane side (*Weaver*).

The body of this vein is quartz, sometimes exhibiting sets of spherical concretions, which often form the centre of a mass of galena. This quartz rock abounds in cavities lined with quartz crystals, and more or less filled with clay, iron ochre, and carbonate of lead. The vein likewise bears galena, copper pyrites, sparry iron ore, and barytes. Blende and iron pyrites appear occasionally. The lead ore produced 70 per cent. of metal, and the copper ore from 10 to 15 per cent. The returns of lead ore from Glendalough were for many years given with those of Luganure, and are included above, so that it is not possible now to separate them.

Mr. Weaver gives a curious example illustrative of this mineral formation. He discovered near the surface a mass of lead ore nearly a ton in

* The production of silver and the value of the lead ore were not returned before 1874.

weight, and on blasting it he found fragments of mica Slate firmly imbedded in the veinstone (Fig. 88).

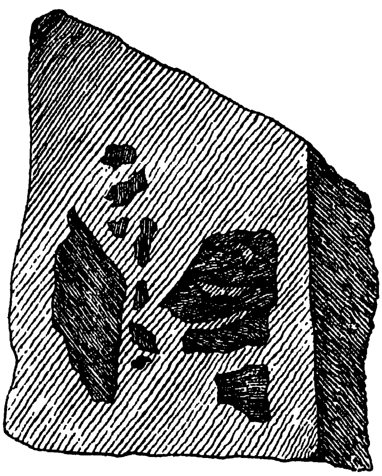

Fig. 88.

Glenmalure.—The lead vein at Ballinafinchogue, which forms an acute angle with the valley, has been traced for a distance of about 400 fathoms, and it is confined to alternating beds of Granite and mica Slate. It is inclined for more than 40 fathoms from the surface to the southward, under an angle of 80°, but for the remaining depth the dip is northward at the same angle. The width varies from 2 to 3 fathoms, and is composed principally of quartz. The ore was originally obtained on the south side of the vein, but it occurs on the north side, and also in the centre; and when these three strings coalesced, they formed considerable bodies of ore. Quartz and galena are the principal constituents, but the vein occasionally produced blende, copper pyrites, iron pyrites, and barytes. The annual produce of ore during a course of several years was, according to Mr. Weaver, 300 to 400 tons, yielding on the average 68 per cent. of lead. Several other veins, but of comparatively small value, occur in this Granite range.

The Clay-Slate district of Wicklow, which is in any way metalliferous, occupies but a small space. It is narrow, and does not extend in length more than 10 miles, ranging from Croghan Kinshela on the south, through the townlands of Knocknamohil and Ballymoneen, Ballymurtagh, Ballygahan and Kilcashel, Cronebane and Tigrony, Kilmacow and Connoree towards the west Aston range, on the north.

The discovery of gold in the Ballinvalley stream, at Croghan Kinshela, has been already named. Mr. Weaver, who was appointed by the Government as commissioner, and who is consequently the best authority on the subject, stated that the gold "occurred in massy lumps, and in smaller pieces down to the minutest grain. One piece weighed 22 ounces, another 18 ounces, a third 9 ounces, and a fourth 7 ounces. The gold was found, accompanied by other metallic substances, dispersed through a kind of stratum composed of clay, sand, gravel, and fragments of rock covered by soil, which sometimes attained to a very considerable depth, from 20 to 50 feet in the bed and bank of the different streams. . . . . At Ballinvalley it was constantly found that the gold was attended by magnetic ironstone, sometimes in masses of half a hundredweight; by magnetic iron sand, by cubical and dodecahedral iron pyrites; and in small pieces and grains, by specular iron ore, brown and red ironstone, iron ochre, *fragments of tinstone crystals*, wolfram, grey ore of manganese, pieces of quartz and chlorite, and sometimes fragments of quartz crystals. I observed and collected also some specimens which show that the gold, magnetic ironstone, and wolfram were frequently intermingled with quartz, and I have also a few specimens which exhibit gold, not only incorporated with iron ochre, but ramifying in slight threads through wolfram.

Some of the gold occurred, though very rarely, crystallised in octahedrons, and also in the elongated garnet dodecahedron."

There is but little doubt that the numerous gold plates found, especially in the South of Ireland, were made from native Irish gold.*

Mr. Weaver asks: "What then is the primary source of these substances, found detached in the beds and banks of the streams?" He answers his question: "It is not improbable that they occur more or less scattered and disseminated through the rocks of the mountain, although it must be acknowledged that no discovery leading to this inference attended the researches of the Government. . . . . We may conceive that the gold and other metallic substances had been detached from their native seat, and have been lodged in their present position, in company with other alluvial materials, at the time of the first formation of soil, and the retrocession of the ocean." The total quantity of native gold collected by Government amounted to 944 ounces 4 dwts. and 15 grains, of which 58 ounces 16 dwts. 1 grain were sold as specimens at £4 per ounce, amounting in value to £236 10s. 8d. The aggregate value of the native and ingot gold was £3,675 7s. 11½d. The discovery of native gold was not confined to Croghan Kinshela. Trials were made at Croghan Moira, at Ballycreen, and at Fannanerin. Although indications of gold were found, no quantity sufficient to pay the expenses of the search was found.

Cronebane.—In this mine, about 1750, some peculiar indurated oxide of iron was found in a metalliferous bed, in which was minutely disseminated native silver. Assay gave about 30 grains of gold in the ounce of silver. The auriferous silver was commonly sold for half a guinea the ounce. The rocks extending into Tigrony and Connorree have been perforated in various directions by the subterraneous works for considerably more than 1,000 fathoms. The Clay-Slate and quartzose Clay-Slate contain subordinate beds, which are usually called *soft ground.* Five such beds of soft ground have been met with—one in Connorree, three in Cronebane, and one in Tigrony The bed in Connorree contains a lode 4 feet thick, consisting of a fine-grained intermixture of galena, antimony, and blende, with pyrites of copper, iron, and arsenic. A similar lode occurs in the more southern bed in Cronebane. The northern bed has yielded some thousand tons of black copper ore, which in the greater depth passes into yellow copper ore. The third bed in Cronebane has proved the most valuable, the greater part of its width being filled with copper ore, chiefly black oxide. The bed of solid ore has varied from 1 to 3 fathoms in breadth; the most productive parts of the bed have in several instances yielded from 10 to 15 tons of merchantable ore from the cubic fathom.

In the twelve years ending 1799 the mines of Cronebane yielded 7,533 tons of copper ore, which gave an average of 8$\frac{3}{8}$ per cent. for copper. A duty of 16s. 6d. British per ton existed up to this time on the importation of Irish ores into Britain. In the next twelve years ending 1811 the produce was 19,342 tons of ore, yielding of copper 1,046 tons. In the year 1808 the ore raised was 2,576; after this, owing to the state of the copper trade, the ore

* "Notes on the various Discoveries of Gold Plates, chiefly in the South of Ireland." By T. Crofton Croker, Esq. (From the "Collectanea Antiqua," vol. iii. London: 1854.)

raised at Cronebane did not exceed a few hundred tons. Sulphur was extracted on the spot by roasting in kilns, and the waters flowing from the mines held much copper in solution. This was separated by throwing scrap iron into it. In Ballymurtagh extensive works were carried on, which is thus described by the Rev. William Henry, who gives a good account of the copper mines* in Wicklow, from which the following extracts are made:—

"The mine which was formerly wrought on, is that of Ballymurtagh, on the south bank of the river. It yielded vast profits to the undertakers; but, on account of some difference between Mr. Whalley and the company, it has been disused for some years past. This is amply compensated by the far richer mines of Crone-Bawn (in Latin *Corona-Alba*, now Cronebane) on the north side of this river.

"Crone-Bawn is a hill of 2 miles in circumference, and, as near as I can guess, about 1,000 feet in height, swelling regularly in the form of a large inverted bowl. The bowels of this hill are, on all sides, full of rich mines, as appears by the shafts which have been sunk in different parts of it. But the principal works lie on the east side, about half-way up the hill. Here I saw several shafts sunk from 50 to 70 fathoms deep. . . . . In sinking these shafts the first mineral met with is an ironstone. Beneath this they arrive at a lead ore which seems mixed with clay, yet yields a large quantity of lead and some silver. Under this lies a rich rocky silver ore which sparkles brightly, and yields 75 ounces of silver out of a ton of ore, besides a great quantity of fine lead. . . . . There are 500 men employed in these mines; their pay is 8d. a day. In order to carry off the water from the mines there are levels carried a great way under ground from the lowest part of the hill. Out of these levels issue large streams of water strongly impregnated with copper." Dr. Henry then tells us, after describing the process of precipitation, "one ton of iron in bars produces a ton and 19½ cwt. of this copper mud and rust. Each ton of this mud produces, when smelted, 16 cwt. of the finest copper, which sells at £10 the ton more than the copper which is made of the ore."

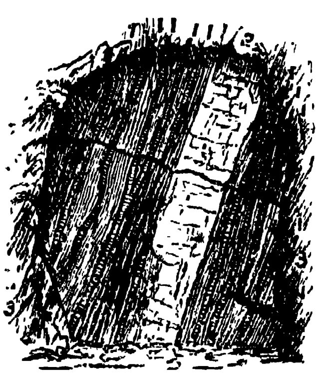

Fig. 89.—Tigrony, Wicklow.

The mines Tigrony and Lower Cronebane are on the eastern side of the Ovoca. The beds of decomposing and variously-coloured Slates, together with the sulphur course and the copper lodes, are the continuation of the deposits of Ballygahan, disturbed by a fault to the extent of nearly 1,000 feet. During the large demand for sulphur in 1841 and 1842 upwards of 2,000 tons of this ore was raised per month. The annexed woodcut (Fig. 89) shows in the light band (2) the iron pyrites—the narrow ribs with transverse lines are "strings" of slightly cupreous iron pyrites.

The copper lodes are very irregular, but more or less parallel to the

* "A Letter from the Rev. William Henry, D.D., to the Right Honorable the Lord Cadogan, F.R.S., concerning the Copper Springs in the County of Wicklow, in Ireland." ("Philosophical Transactions," vol. xlvii., for the years 1751 and 1752.)

pyrites course; they commence almost immediately on its south wall, and are sometimes seven in number, besides occasional intermediate ribs, within a width of 20 fathoms, so that the ground is worked away in *stopes* of 14 or 15 feet wide, for considerable distances (*Smyth*).

In 1846 the work was concentrated upon the copper lodes, but subsequently the pyrites ores have been largely extracted and sold from the Tigrony sett.

	Copper Ore. Tons.	cwts.	Copper Precip. Tons.	cwts.	Pyrites. Tons.	cwts.
1872	—		27	0	19,232	10
1873	—		23	0	16,318	10
1874	22	4	—		9,486	0
1875	—		29	5	6,588	0
1876	—		59	6	4,937	0
1877	88	0	70	10	1,997	7
1878	63	0	35	3	3,353	16
1879	—		28	0	3,191	0
1880	—		18	11	5,735	0
1881	29	0	22	0	6,790	0

Ballymurtagh mine has a large metalliferous deposit which dips into the Slate at angles of 40° to 60° south-east, and consists, at a short depth from the surface, of 12 feet in width of granular iron pyrites altogether free from *gangue* or veinstone. This deposit is not bounded by distinct walls, but has gradual interstratifications with the Clay-Slate. On the north, to the distance of 100 fathoms, and on the south, for 20 fathoms, parallel veins of copper ore have been met with. The iron pyrites has not been found in available quantities at a greater depth than 100 fathoms; it appears to become thinner at 80 fathoms from the surface, and then to unite with the copper lodes on the south, forming together, at the 56-fathom level, a "bunch" of copper ore 24 feet in width. This vein was, in one spot, by the addition of numerous bands of greater or less thickness, increased to nearly 60 feet.*

The ore, which is the ordinary copper pyrites, is not gathered into a lode, but it is interlaminated so delicately, as to appear often in fine films, forming part of the adjoining rock. On the surface of the hill, about 120 fathoms to the north of the principal vein, a course of iron pyrites was found of remarkable size and solidity, averaging about 24 feet.

The produce of Ballymurtagh mine has been as follows in the years named:—

	Copper Ores. Tons.	Pyrites. Tons.	Coppery Pyrites.† Tons.	Copper Precip. Tons.
1844	7,130	9,575	—	—
1849	7,783	9,582	—	—
1856	450‡	21,861	4,432	—
1857	500‡	31,598	3,000	5
1858	—	35,253	3,250	—
1859	—	37,952	3,050	—
1860	—	40,500	4,000	—
1865	450‡	43,400	2,000	—
1870	—	19,149	—	13
1875	155‡	2,886	—	—
1880	—	1,858	—	—
1881	—	945	—	—

* This information is obtained from the excellent memoir "On the Mines of Wicklow and Wexford," by Warington W. Smyth, M.A., F.R.S., in the "Records of the School of Mines."

† Coppery pyrites contains from 35 to 40 per cent. of sulphur and 1½ per cent. of copper. Some samples contain as much as 3½ per cent. of copper. Much of the Irish pyrites contains traces of gold, which is separated at the works around Liverpool.

‡ These were the quantities of copper ores sold at Swansea.

Mr. W. W. Smyth relates the following instance of a great fall of matter in this mine:—

"In 1835 a great fall of the solid iron pyrites occurred from the roof of the 18-fathom level: a mass 30 fathoms long and 20 fathoms deep (at an average of 10 feet wide, weighing nearly 30,000 tons) broke away and crushed through all the levels to the bottom. The previous sounds of rending, and the smell of sulphur, diffused by the friction, warned most of the men to escape, and even the rats, which were living in great numbers underground, fled to the surface. Eighteen men, however, who took refuge in a freshly driven gallery, were immured at a great depth from the surface, and after a couple of days passed in the most frightful anxiety, were extricated by an orifice accidentally left, and found to extend through the heap of ruins."

In *Ballygahan* mine, also one of the Ovoca mines, the general characters of Ballymurtagh are repeated.

Shallee.—At Shallee a curious series of north and south lodes occur. This point is 3 miles west of the calamine deposit, and upwards of 100 of these small veins have been wrought, all of them open-cast, and none of them to a greater depth than 7 fathoms. In some cases they are so close together that the "country" left standing between them has no greater thickness than 3 feet. They occur mostly in divergent bunches, and are usually in the vicinity of the Shallee fault, but, strangely enough, do not seem to run into it, cross it, or be in any way connected with it. Their appearance is quite exceptional, but they cannot be said to belong to the stockwerk family. They are always found to the south of the fault in the Devonian Sandstone.

Silvermines.—The Shallee fault is traceable for several miles, but its throw is variable and not always easily estimated. Its valuable mineral contents are lead ore (argentiferous), copper ore (chiefly pyritous), blende, calamine, and sulphur. This arrangement of enumeration is the same as the progressive occurrence of the various ores, as the fault is followed eastwards on its stroke from Shallee to Silvermines. The blende mostly occurs scattered through the pyritous rock in inconsiderable quantities, while the occurrence of the calamine is still less frequent. The width of the mineral matter filling this fault varies from a few feet to several fathoms. At a little to the north of the fault, at Silvermines, a series of "old men's" workings have at some previous time been carried on, and report states that a good deal of argentiferous galena was extracted. Be this as it may, the slags found in heaps at this spot attest to the carrying on of smelting operations. The mining works were scattered over an area of several acres, and the whole surface of the ground for that area is found covered with ochrey matter and stones of calamine, this mass being in some places a foot deep. It is worthy to note that a valuable mineral, so extremely widespread and apparent, should have escaped observation for so many years; however, about the year 1859, samples were sent to Professor Apjohn, when the mineral was determined to be an earthy carbonate of zinc, and explorations were at once instituted. The result of these have shown a most extensive bed of zinc ore, varying from 10 to 60 feet thick, and covering a known area of several acres. It seems to occur as an inter-

foliation between the true Limestone beds and the dolomite, while it dips north with the strata at an angle of from 20° to 30°.

*Glandore Mineral Channel, County Cork.**—The original fissure was filled with conglomerate stuff made up of the country rocks. The second fissure, which ran very regular, that is, more or less parallel to the walls of the first, was filled with iron ore. There were strong reasons for supposing that the iron ore was only the back, or gossan, of a copper ore. If such was the case, the fissure must have been first filled with copper ore, while the iron ores were the result of chemical changes. The third—a very irregular fissure—sometimes running with the iron ore, at other times across it, or leaving it altogether, and being in the conglomerate, was filled as far as can be seen with manganese ore. This channel was of no great width, but others are much more considerable, such as those at Ovoca, County Wicklow. In these wide channels of faulted rock a newer fissure may form, or two or more quite independent fissures, as shown in the diagrammatic plan, and section, Fig. 90.

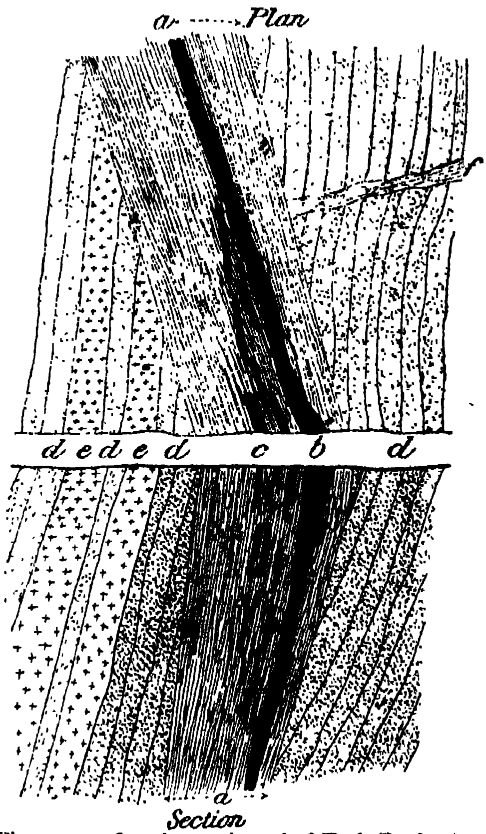

Fig. 90.—*a*, first fissure-channel of Fault Rock; *b*, main lode, second fissure; *c*, yellow copper ore lodes, third fissure; *d*, Country Rock; *e*, felstone in Country Rock; *f*, fault in Country Rock that does not effect the channel of Fault Rock.

North and south of the fault are the country rocks, which strike and dip independent of it. In the channel *a* is "*the man's lode*," supposed to fill a fissure second in age, while coinciding with the structure of what Mr. Kinahan calls his third system, which consists of copper ore lodes.

Even mineral lodes may be made up of fissures within fissures, some of these being nearer than others, and appear to have filled cracks which may probably have been produced by shrinkage. Mr. Kinahan mentions another class of faults, consisting of masses of the native rocks ruptured and displaced, but not entirely broken up. In places in County Wexford, in faults of this class, there will be found unbroken portions of beds of Limestone, and other rocks, running continuous for many yards, some being of such length that they may easily be supposed to belong to undisturbed strata; but that they are in wide faults is proved by their running transverse to the strike of the rocks at both sides of the fault.

In the preceding pages several examples of the characteristic features of

* "Notes on Fault-Rock." By G. Henry Kinahan, M.R.I.A. ("Transactions of the Manchester Geological Society," vol. xvii. 1882–83.)

lodes, or veins, have been given. There are still some conditions in connection with the filling of lodes, and the dissemination of minerals, which appear to require additional notice.

Parts of many lodes consist of a succession of plates of mineral substances, varying much in their continuity, and to a certain extent parallel to the sides of the fissures, between the walls of which they are included. These vertical plates, which vary from a few lines to many inches in thickness, are known to the miners in Gwennap, and in other parts of Cornwall, as *combs*, and a lode is said to be a *comby lode*, when composed of such vertical plates.

Sir Henry de la Beche has paid considerable attention to lodes of this character, and he makes some most pertinent remarks on the formations of the *combs*. He especially refers to a drawing of a lode in Wheal Catherine (Fig. 91) mine on Carn Brea, near Redruth: "All the *combs*, or plates," he says, "have the points *turned inwards*, and all are readily separable from each other by a moderate blow along the surfaces—1, 2, 3, 4, 5, 6, are ochreous indurated clayey substances which separate the combs *a b c d e f* from each other. From all we know respecting the filling of cracks by crystalline substances, deposited from solutions in them, we should conclude that the breadth of each comb constituted the whole width of the fissure, at the time of the substances of which the comb is composed were crystallised upon both walls of the fissure as bases, so that the crystallization gradually met in the centre. If this be correct, we should have six consecutive openings of the fissure for the contents of the lode here represented, so that 1 and 6 constituted the walls of the lode, or the sides of the fissure, when the combs above noticed were all formed."

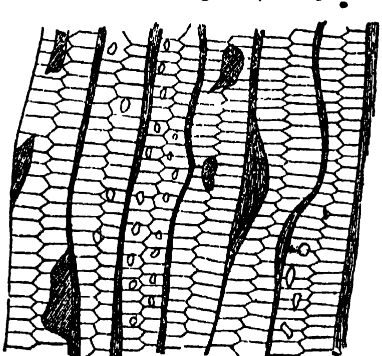

Fig. 91.—A Comby Lode.

This is an ingenious way of accounting for a remarkable example of this comby structure. The principal difficulty is to explain the enormous force required to open such a rock fissure. We know that the crystalline force exerts an immense mechanical pressure, but it is doubtful if the force is equal to the movement of a solid rock in its natural bed, surrounded on every side with the most coherent masses. It must be confessed that it is not easy to suggest any other method. We may, indeed, suppose that the crystals first formed upon the walls—the sides—of the fissure, and that the cavity was filled with clayey matter, upon which the second layer of crystals began to form and gradually dovetailed into the first layer. The clay wall would afterwards be removed by the action of water which would increase in power, as the progressing crystallization rendered the passage narrower and narrower.

Sir Henry de la Beche gives a second example from a lode in Wheal Julia, near Binner Downs, Crowan. "In this" (Fig. 92), he says, "we perceive more irregularity than in the preceding figure, and in the comb *e* we

see that crystals of sulphide of zinc, intermingled with bi-sulphide of copper, were formed on each side before the quartz was deposited, and such in crystallization is the centre of the comb. The *vug* or cavity at *g* shows that the crystallization had not filled up the space in that direction, and the group of pointed crystals in it exhibits the general appearance of those parts of the fissure where the crystallization had not met from the sides, and by interlocking filled up the cavity."

The plates thus formed are actually separated from each other by a thin deposit of clay. After the deposition of the metallic ore there appears to have been a period of repose, during which the earthy matters have subsided from the water flowing slowly through the fissure. It then, however, frequently happens that a different ore is deposited from that which first fixed itself against the walls of the lode. Perhaps the first deposit may have been iron pyrites, then a thin sheet of clayey matter. It not unfrequently happens that the succeeding plate is of copper ore. This goes on for some time, and on both sides of the lode, and then again, owing to some change, which is due to conditions we are unable to trace, another period of repose, or at all events a change of condition, takes place, and sulphide of zinc (blende) is deposited, or sometimes some earthy minerals take the place of the metalliferous ones. This goes on slowly, each side of the lode usually exhibiting the same formation, until the middle of the lode is reached. It then becomes evident that a current of water has continued its steady flow, and when the lode is opened, streams of very clear water usually flow out, and clayey matter, with frequently crystals of quartz, is found surrounding the vacant spaces.

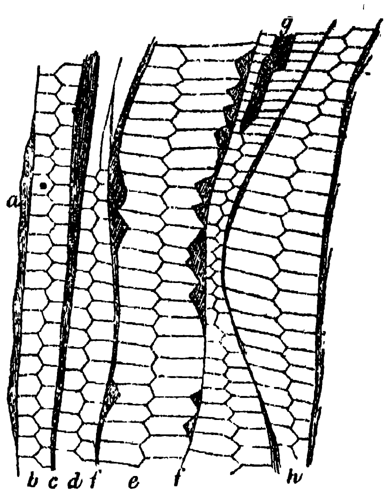

Fig. 92.

a Bisulphuret of copper and sulphide of zinc.
b. Comb of quartz.
c. *Wall of indurated argillaceous matter.*
d. Comb of quartz.
e. Large comb of quartz, with blende and yellow copper ore, *f f*, on both sides.
g. *Vug*, or cavity in another comb of quartz.
h. More solid comb of quartz.

It is scarcely necessary to remark that the "mass of indurated argillaceous matter" *c*, appears to furnish a base, upon which a crop of crystals might form and produce the required comby structure.

"A close inspection of the quartz crystals forming combs, by interlocking towards the central parts, often shows the gradual increase the crystals have received in the direction of the axes of the prisms, and sometimes small sprigs of copper ore or blende may be seen entangled among them, in lines corresponding with surfaces which existed during the formation of the comb, as if, while the crystallization of the quartz was effected, the silicious solution sometimes contained the elements of bi-sulphide of copper, and was frequently without them, or, if it always contained them, that conditions were often unfavourable for their deposition on the sides of the cavity holding the solution" (*De la Beche*).

Fig. 93 is another example of a comby lode from Carn Marth. In this drawing the "combs" are slightly exaggerated—although in position, &c., strictly true—for the purpose of showing more prominently the peculiar characteristics of this description of lode. The several layers are distinctly marked. The student may, therefore, readily note the order in which each layer was produced. In this example it would appear as if the mass of copper ore marked E had been an opening which had been filled in, at a later period than any of the other bands. There is a certain inequality in the number of layers on either side, counting from the walls of the lode, which will scarcely agree with the explanation given by De la Beche.

The layers composing a metalliferous lode are sometimes composed of

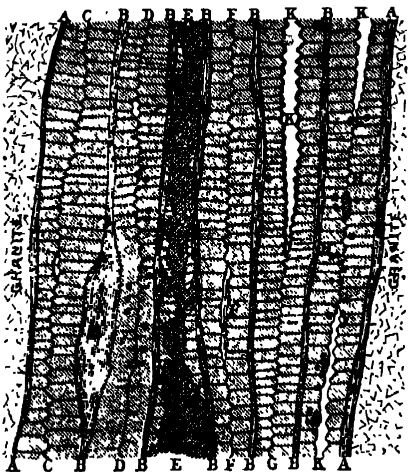

Fig. 93.—Comby Lode from Carn Marth.

A A. Walls of lode. *Granite.*
B B. Clay partings.
C. Quartz and purple fluor.
D. Quartz with yellow copper ore.
E. Quartz—dark shade copper ore.
F. Quartz and purple fluor.
G. Quartz.
H H. Quartz, with a little copper ore.
K K. "*Vugs*"—cavities.
Black spots and patches are copper ore.

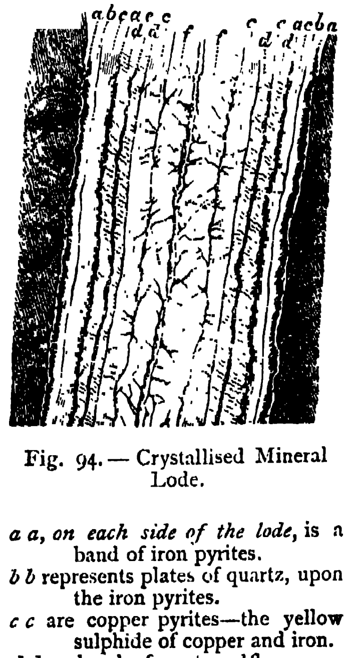

Fig. 94.—Crystallised Mineral Lode.

a a, on each side of the lode, is a band of iron pyrites.
b b represents plates of quartz, upon the iron pyrites.
c c are copper pyrites—the yellow sulphide of copper and iron.
d d are bands of quartz and fluor-spar.
e e are bands of quartz, containing veins of copper ore.
f f are crystalline layers of quartz, with strings of copper ore.

different substances, as in the other woodcut (Fig. 94). Unless the crystallization in the lode shows that the resulting solid ore has been formed by additions from the sides inwards, we know not what explanation can be given of the conditions. We cannot be certain that all such lodes have been produced by successive openings. Without doubt much difficulty surrounds this question, which can only be solved by a most careful examination of a considerable number of analogous phenomena in lodes, formed in rocks of varied character, and passing through dissimilar strata. The uniformity of this crystalline lode is remarkable.

Werner notices a specimen from Segen-Gottes at Gersdorf, in which, reckoning from the middle—composed of two kinds of calcareous spar—thirteen layers of different minerals are arranged in the same order on each side of the vein. In the southern vein, the two beds which are next the rock

are quartz; next to this on each side is sulphide of zinc, mixed with iron pyrites. This is followed by sulphide of lead, carbonate of iron, another layer of galena, then carbonate of iron, again galena, carbonate of silver, red silver ore and sulphide of silver. The most recent portion, or the central part, being calcareous spar.

M. Fournet* gives the following example of a lode varying with the changes in the adjoining rock: The Winzel lode, at Furstenberg, runs nearly vertical from north to south across many beds of gneiss, about 60 feet thick, dipping east. Each of these beds forms a distinct variety of rock. The first is very micaceous; the second passes into argillaceous Slate; the third is hornblendic; and, in the fourth, scarcely any mica can be detected. This lode is *heaved* in depth to the westward by several cross courses, and it was between two of these cross courses, distant from each other about 40 fathoms, that it exhibited those riches for which it was celebrated. In the first bed of gneiss, the lode merely formed a nearly imperceptible string of clay; in the second it suddenly acquired a thickness of from 12 to 18 inches, and was composed of sulphate of barytes, antimonial silver, red silver, and argentiferous grey copper ore. The antimonial silver was always found in large masses. In the third bed, the thickness of the lode was preserved, and the sulphate of barytes continued in it, but the silver ores disappeared, and a little sulphide of lead was the only ore found. In the fourth bed the silver ores became as abundant as in the second; but they gradually disappeared in depths and were replaced by selenite, a little sulphide of lead, and some traces of native sulphur. We have nothing in this country which presents such striking changes as those described by Fournet; but we have many examples of a similar description.

Fluor-spars, or crystallised fluates of lime, are found in great beauty and variety in the mines of Derbyshire. The most noted mines for this interesting mineral are:—

Ashover .	. Fallhill and Westedge mines.
Bonsal .	. Ball-eye mine.
Bradwell	. Picture End, Smalldale Lead and Tanner's Venture.
Castleton	. Cliff-side, Miller's Pipe, Odesi, Old Tor, and Water-hull.
Crich .	. Crich-cliff.
Cromford	. Ash-cross and Gang.
Matlock .	. Dimple, Knowle's, and Seven Rakes.
Overton .	. Gregory.
Roston .	. Birchwood Park
Wirksworth	. North Cliff, Orchard, Ratchwood, &c.

At several of the fashionable places in Derbyshire fluor-spar ornaments are manufactured on a large scale, especially from the purple variety. There is also a consumption of the yellow and inferior kinds of this spar, derived principally from the Crich mines, as a flux for melting lead and copper ores.

The annexed woodcut, of a Fluor-spar lode, is instructive. Fluoric acid is one of the so-called elementary bodies. In many respects it resembles chlorine. Indeed it forms one of a group which appears to have much in common, including bromine and iodine. Fluoric acid—the combination of hydrogen with fluorine—unites with lime with much avidity, forming a fluate of that

* Fournet, "Études sur les Dépôts Métallifères." (D'Aubuisson's "Traité de Géognosie," 2nd book, vol. iii.)

earth. It also readily unites with silica, as may be proved by the way in which it etches glass. There is no doubt that fluorine plays some very important part in the chemistry of nature. An interesting field of inquiry lies almost untouched for the investigation of the chemist. In studying the phenomena of mineral lodes, we constantly discover evidences of the action of hydrofluoric acid; but we have not yet isolated fluorine, or determined the

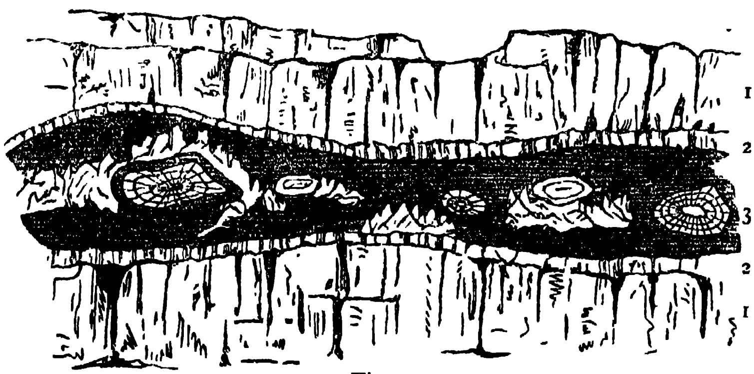

Fig. 95.

1. Limestone. 2 2. Blue fluor-spar. 3. Mixture of clay, yellow fluor-spar, and sulphate of barytes, with nodules of "Blue John."

variety of combinations with earths and metals into which this important element enters.

"Blue John" is a name given to a dark purple concretionary variety of fluor-spar (fluate of lime). Fig. 95 is a section of a part of one of the veins containing this beautiful mineral. They are generally irregular flattened pipes, running almost horizontal, then bending sharply up or down across the bedding. At the point where this drawing was taken the lode was nearly flat. Its upper and under surface was lined with coatings of blue fluor-spar, and the space between these was filled in by a mixture of reddish-brown clay with yellow fluor-spar and nodular sulphate of baryta. In this were scattered, here and there, concretions of the Blue John arranged in concentric layers of different tints and in radiated masses. Nodules of Blue John are also found in the solid Limestone around the lodes.

An interesting variety of fluor-spars are found in Allendale, in Weardale, and in Alston Moor. Crystals of considerable difference of form are produced in the different lead mines: cubical crystals, with the edges sometimes bevelled, octohedral, polygonal, and very irregular. The colours are very numerous: red, green, blue, yellow, purple, violet, colourless, and all gradations, from very pale to almost black; often of a drab surface, composed of different minute crystals, and not unfrequently speckled with marcasite, very commonly found mixed with lead ore, spar, &c., sometimes studded with brilliant quartz crystals and with finely crystallised galena. The fluorescence of this spar, and similar optical phenomena, seen in other substances, have been most carefully investigated, and fully described by Professor Stokes, in the "Transactions of the Royal Society."

In connection with the Derbyshire lead lodes, and their relation to the *Limestone* and the *Toadstone*, several important particulars relative to the lodes

on Crich Hill have been furnished by Mr. E. M. Wass, of the Lea Lead Works, Matlock.

"In the 'Pearson's Venture,' situated on the west side of Crich Hill, the Toadstone was reached at a depth of about 80 fathoms; its thickness was 11 fathoms. This was a most productive mine, both above and below the Toadstone, but at a depth of 115 fathoms the vein became contracted and poor, and this ground being heavily watered was abandoned.

"The 'Bacchus pipe' is also on the west side of the hill; there the Toadstone was found after sinking 75 fathoms, and its thickness ascertained to be 20 fathoms.

"At the 'Glory mine,' north of Crich Stand, a much wrought and in past years very remunerative mine, the Toadstone was discovered 30 fathoms from the surface, and found to be 9½ fathoms thick. The lowest workings at this mine were 135 fathoms from day; the veins, however, diminished so materially in strength and productiveness the lower they were followed as to discourage trial requiring pumping machinery.

"The 'Old End mine,' on the eastern slope of the hill and north of Crich Stand, has been explored to a greater depth than any of its neighbours. The Toadstone there was arrived at in 50 fathoms; the deepest workings went down about 152 fathoms."

In these mines all the lead lodes became poorer the lower they were followed; and a glance at the map of the Geological Survey will show that lodes are more numerous in the upper than in the lower beds of the Limestone. Mr. Wass says: "My own experience certainly confirms what has been frequently advanced, namely, that *as a rule* our veins are stronger and more productive in the upper than in the lower parts of the Limestone." We are not in possession of facts enough to justify us in making any sweeping generalization on this subject, but all we do know seems to point to a falling off of the contents of the lodes as soon as the lower Limestones are entered.

Barytes Mines.—Barytes enters largely into the component parts of the lead lodes of Derbyshire. This earth is known as the crystallised sulphate of barytes, as Terra Ponderosa, as heavy spar, as cauk, or tush (Dr. Woodward, in his "Method of Fossils," terms this mineral *croyl stone*). Barytes occurs also in considerable quantities in Shropshire. In 1881, Snaibeach produced 559 tons; Weston, 523 tons; and Wotherton, 2,195 tons. In Northumberland, in the same year, Fallowfield produced 2,906 tons, and Settlingstones, 2,512 tons. Raygill, in Yorkshire, produced 2,017 tons. Derbyshire, from 44 lead mines, gave 5,140 tons. Ireland, from Duneen Bay, gave 3,786 tons. The total production of Barytes—sulphate and carbonate—in the United Kingdom in 1881, being 21,313 tons, of the value of £23,894.

The following remarks on the formation of barytes in the Dufton mines are by Mr. William Wallace, who was for a considerable time the manager of them: "The sulphate of barytes is the principal mineral found in Dufton-Fell mine. It is deposited chiefly in flats in the Limestone strata, mixed with lead ore. The range of this mineral, in depth from the surface, is, however, very limited; the most extensive deposits in the flats exists near the surface; and are chiefly restricted to the Tynebottom and Jew Limestones. The quantity of barytes deposited in the Tynebottom Limestone,

from its line of outcropping to the cross vein, is very large. The Limestone has been removed to a width of 180 feet or more, and the space filled with this mineral and lead ore. The process of either removing and substituting Limestone and barytes was probably very slowly effected. If the former was the case, both processes must have been going on at the same time, as no large spaces could have remained unfilled with barytes, after the Limestone was removed; for the bed of soft shale which rests upon it would have fallen into them. The space originally filled with Limestone has, however, in some places, contracted a little; for the shale had given way, forming horizontal cracks or openings, seldom more in width than the thickness of a penny-piece. These openings are all filled with lead ore. What is also remarkable is that the smallest particle of barytes mixed with the thin sheets of lead ore could not be detected—it was simply pure lead ore seamed into pure unchanged shale. This occurred on the south side of Hard Ark vein, where not less than 54 feet in width of Limestone from the vein has been removed, and all the space, except the small contraction occasioned by the formation of the spaces, in the bed of shale, filled with barytes and lead ore. An instance of shale having fallen into the open space during the formation of flats came under observation in the Tynebottom mines in Alston Moor. In these mines the plate or shale partakes more of the character of hard rock than it usually does, and is of a peculiarly mottled grey colour. At one place it was found in irregular masses filling up the space which had been occupied by Limestone, and all the interstices between the broken lumps were filled with carbonate of lime and lead ore."

The extent of barytes in the Tynebottom Limestone is greater than that of lead ore. At the extreme east end of the mine the quantity of barytes deposited in the Tynebottom Limestone, in connection with Hard Ark and Dobson's veins, though large, yet only forms a small proportion of the quantity deposited in connection with Barrow's vein near the outcrop. A similar fact is connected with the deposit of barytes in the Jew Limestone. It is also only in connection with the richest deposits of lead that the most transparent crystals of barytes are formed. Farther east, and towards the limits of the lead ore deposits, the crystals of barytes are perfect in form but invariably opaque.

Westgarth Forster says he "has seen *cauk* spar of a dead white, but commonly it is of a yellowish or a reddish white, or of a flesh-colour, sometimes crystallised and transparent as at Dufton-Fell in the county of Westmoreland."

In the Limestones below the Jew, and near the surface, only very small quantities of lead and barytes have been deposited. In the Smiddy Limestone, Barrow's vein contains no barytes and very little lead ore. The vein is filled with ferruginous rubbish. Directly below the vast deposit of barytes and lead in the Tynebottom, Barrow's vein contained no barytes or lead. The Limestone on each side of the vein was carbonised or crystallised into a substance almost as hard as adamant. The making of an ordinary rise, in a portion of the ground, cost £45 per fathom. No sparry substance was found in the vein. The deposit of barytes and lead in the Melmerby Scar Limestone is limited to a small portion of Barrow's vein near the surface and close on the east side of the Pennine Fault. Through the whole extent

of this ground no flats are formed, nor are any lead or barytes found in the vein, which after the barytes disappears is simply filled with clay and rubbish.

There is a vein in *Welhope*, in the county of Northumberland, containing the common *cauk* spar, or sulphate of barytes, in the upper beds, which changed its matrix in the Great Limestone, and contained *aerated* or carbonated barytes. It lies mostly in cavities, or *shakes* of the vein, in round balls, and when broke, it is striated as diverging from the centre (*Westgarth Forster*).

In Robinson's Limestone, which may be considered as the upper part of the Melmerby Scar, and also in the Smiddy Limestone, Dobson's veins could not be identified. They existed simply as very small cracks or fissures in the rocks which had sustained no chemical change, though only a very short distance farther east the space which the Jew Limestone lead occupied between the two veins was entirely filled with barytes and lead ore.

The Hard Ark vein ceases to exist on the east side of the outcropping of the Tynebottom Limestone. White Rake and Barrow's veins are the only veins of any magnitude which extend to the Pennine Fault. Extensive flats have not been formed in the Limestone sides of White Rake vein. The lead ore and barytes, of which latter substance the vein contains a great deal, is, however, only small, when compared with the deposits of this substance in flats on the sides of Barrow's vein. The old works in White Rake vein are in a great measure closed; in consequence I have had few opportunities of making personal observations.

General Résumé of the Subject.—Mr. John Taylor—to whom mining is under a great debt for the introduction of a superior system of working mines, and for numerous improvements in the machinery employed—in a Report on Mineral Veins* remarks: "Kirwan supports the doctrine that some veins were originally open, as appears from the rounded stones and petrifactions found in them. Thus in the Granitic mountain of Pangel, in Silesia, there is a vein filled with *globular basalt.* So also in veins of Wacken, in Joachimsfahl, in Bohemia, trees and branches have been found. But he deems it improbable that all veins were originally open to day, and filled from above. He inclines to the theory of veins being filled by the percolation of solutions of the metals and earths."

Mr. J. Taylor, in concluding his report, carefully summarises all the hypotheses which have been from time to time promulgated. His remarks are much to the purpose:

"The greatest controversy relates as to the mode in which veins have filled. Werner, and the mining authors on whom he relies, drew their inferences as to deposits from metalliferous veins. Hutton, Playfair, and others regarded chiefly those of a trapean character. That certain veins have been filled by injection from below, and with matter in igneous fusion, seems to be rendered certain by evidence, which is clearer than most we possess on such subjects, and must be admitted at once. Thus when we see a *trap dyke*

* "Report on the State of Knowledge respecting Mineral Veins." By John Taylor, F.R.S., Treasurer of the British Association for the Advancement of Science. ("Transactions of the British Association," Cambridge, 1833.)

traversing a bed of coal, and charring the combustible matter, and affecting the rock itself with visible effects of great heat, we must admit the cause assigned. In answer to this the question is asked, why, for instance, if the ores were forced from below, did the power which injected them just limit itself to raising them within a short distance of the surface, for where shall we find an instance of their being protruded above it? The quartz reefs, which may be quoted as examples of mineral veins—for essentially they are such—are examples of the very protrusion which is supposed not to exist. If the matter enriching our lodes had been derived from below we should expect, by a nearer approach to the centre of the earth, to find metallic riches more abundant. The hypothesis of filling up veins—fissures—by precipitation, is supposed to be defective in not being able to show what menstruum could render such substances soluble in water. This inquiry has been already answered by the facts that the waters of the ocean and mineral springs do hold most of the matters found in mineral lodes in solution."

It has been urged that the supposition is absurd, that water cannot arrange its deposits in places highly inclined. We do know that silica is soluble in water, and that crystals of that mineral do arrange themselves on the sides of vessels in planes highly inclined. Stalactites of chalcedony are by no means uncommon. In the cliffs at Perranporth is a vein of chalcedonic quartz, at least a yard wide, which is made up of vertical bands. Again, we have examples, as have been already shown, of quartz veins, with iron pyrites and copper ore in veins which are very slightly removed from the vertical.

Those who object to the idea that veins may be filled by matter in a state of igneous fusion, as well as those who find great difficulty in supposing that water was an active agent in the formation of lodes, are driven to adopt the view that metallic vapours, and exhalations from vast depths, have been condensed on the sides of cracks, and this view is borne out to a considerable extent by the vents through which, in California, the hot waters, steam, and vapours escape. The hypothesis of filling up by sublimation would seem to require that the deepest portions of the veins should be the richest. Shallow as mine workings have been, there is every appearance of their having gone below the richest deposits of the metals. "It is impossible," says Mr. Taylor, "to say that greater deposits may not exist still lower down; and though veins have not been traced to their termination, they have in many instances been pursued until the indications of metallic produce have become faint and hopeless."

The relation which the contents of a vein bears to the nature of the rock has been already dwelt on, but the following general statement by Mr. J. Taylor cannot fail of being acceptable: "In the older rocks, we see the same vein intersecting Granite and Slate; it is itself continuous, and there is no doubt of its identity, and yet the contents of the part enclosed by the one rock shall differ very much from that which is found in the other. In Cornwall a vein that has been productive of copper ore in the Clay-Slate, passing into the Granite, becomes richer, or what is more remarkable, furnishes ores of the same metal differently mineralised. Veins in some cases cut through the Elvan courses, as well as the Clay-Slate enclosing these porphyries; the ores are rich and abundant in the latter, in other instances they fail altogether.

Less striking differences in the structure of the rock affect the contents of the veins. The miners often rely upon a *change of ground* as an assurance of improved conditions in the lode itself. In the lead mines of the northern counties this is remarkably shown. Indications of this have already been noticed, but a statement made by Westgarth Forster may with advantage be repeated: "The lead-producing rocks occupy a thickness of about 280 yards. Nine of these beds are of Limestone and eighteen are of silicious Sandstone, locally termed Gritstone, and the remainder are black shale '*plate*' with thin beds of coal. The fissures forming the lead veins are common to all, but lead ore is only found in particular beds. Where the lode passes through the black shale little or no lead ore is found. In the Sandstone the veins are more productive, but it is only in one of the beds of Limestone that lead ore is found in large quantities." Mr. John Taylor concludes a report by stating: "That metallic ores are found to repose in rocks which seem congenial to them, and that their combinations are modified by changes in the rocks, will not, I think, be disputed by practical miners, or by those who have most narrowly searched into the hidden recesses of the Earth."*

Quartz occurs in nearly all mineral veins; it may be distinguished from calcareous spar by its crystallization. Several species of this kind of spar are found, sometimes cubical, and often tabulated. Much shoots into prismatic crystals, so pure and pellucid as to resemble the diamond, differing from that gem, however, by its hardness, and its less refrangibility. Quartz is often found in *Elvan courses* in Cornwall in double-pointed crystals, indeed they may be regarded as a characteristic of these porphyritic dykes. These crystals are found abundantly in the neighbourhood of Wheal Coates in St. Agnes, and also in the Elvan, on Roborough Down, near Tavistock. Mr. Prideaux† described their occurrence in a bed of porphyry: "Running from nearly opposite Hoo Meavy to Bickham is a bed of singular porphyry, with no defined dip, boulders of which are strewed about the Down so extensively, as to have acquired the name of Roborough Down stone. It is almost white on fresh fracture, becoming brown by the weather, and is full of small cavities.

* To illustrate the comparative bearing of the different beds in the manor of Alston, Mr. Thomas Dickenson, Moor-Master for Greenwich Hospital, got out for Mr. John Taylor an exact account of the ore produced from each bed in all the mines of the manor in 1822:—

LIMESTONE BEDS	Great Limestone	20,827 bings of 8 cwts. each.	
	Little Limestone	287	
	Four-fathom Limestone	91	
	Scar Limestone	90	
	Tyne-bottom Limestone	303	
			21,688 bings.
GRITSTONE BEDS	Higher Slate sill	107	
	Lower Slate sill	289	
	Firestone	262	
	Pattinson's sill	259	
	High coal sill	327	
	Low coal sill	154	
	Tuft	306	
	Quarry hazel	44	
	Nattrass gole hazel	21	
	Six-fathom hazel	576	
	Slaty hazel	18	
	Hazel under Scar Limestone	2	
			2,365 bings.
	Whole produce of the manor		24,053 bings.

† "Transactions of the Plymouth Institution," vol. i. p. 30.

. . . . It is thinly disseminated with minute crystals of translucent quartz, and the cavities which appear to be cubical when regularly formed, contain in some instances remains of the matter with which they were irregularly filled. Quartz is very generally found lining the hollow spaces (*vughs*) in lodes. Sometimes the lodes consist entirely of quartz, forming the lodes, or in layers of white crystalline quartz, abounding in cavities, often lined in the most beautiful manner with crystals of silica, and frequently enclosing broken fragments of the Slate rock. These pieces of Slate are generally sharply defined, and are commonly very uniform in their positions, frequently showing, however, a flinty character. There is a striking difference between the nature of the crystalline quartz, in the vicinity of fossiliferous rocks, and that which occurs near Granite. In the former the *vughs* are very numerous, and usually small, and the quartz crystals with which they are encrusted are very small and of a snowy whiteness. In the latter the cavities are less frequent, of a different size, and have often a high degree of transparency."

These *vughs* are often of great size. In Dolcoath mine, one was broken into which was from 18 to 20 fathoms in length, 3 fathoms high, and from 4 to 9 feet wide. This occurred in the main lode, and was, indeed, a series of small caverns opening one into the other. It was filled with vesicular carbonate of iron with quartz crystals.*

Between the 110 and 120 fathom level in the Consolidated mines, Gwennap, a very extensive "vugh" was discovered in 1835. It was nearly 40 fathoms in length and from 1 to 2 fathoms high. The direction was nearly horizontal, the lode both above and below producing good ore.†

Many of the cross veins (*cross courses*) are mainly made up of quartzose varieties of the contiguous lodes, but they differ from the lodes in being seldom metalliferous, and in the crystalline character of the quartz. The jointed structure is another characteristic of the *cross veins*, but this is confined to their quartzose portions alone. They also exhibit an irregular crystalline arrangement of the quartz, *the axes of the crystals being disposed across the vein.* Mr. W. J. Henwood remarks: "This crystallization seldom or never presents a symmetrical form, but the whole consists of a congeries of small crystallised masses bounded by faces, which are disposed at right angles to the direction of the vein; they intersect in almost every imaginable manner."

Westgarth Forster says: "Most of the mineral spars are frequently found shot into prismatic, cubic, hexagonal, or other figures. These figured crystals are generally transparent and very beautiful. It is a great curiosity to behold the inside of some of the large cavities in which they are formed. Those caverns, lined with crystals, are frequently met with in hard mineral veins, and they are generally called by the miners *shakes*, *lochs*, or *loch-holes*." In continuation Mr. W. Forster says: "The magnitude of those caverns is generally in some proportion to the capacity of the veins in which they are found, and the insides of them frequently exhibit all the variety, beauty, and splendour of the most curious grotto work.

"There is, commonly, a hard, concreted, stony crust, called *druse* or *riders*

* Mr. Rule, "Cornwall Geological Transactions," vol. i. p. 25.
† Mr. Burr, *The Mining Review*, July, 1835.

by the Alston Moor and Allendale miners, adhering to the inside of the cavity, out of which, as out of a rock, an innumerable multitude of short prismatical crystals are shot, which sparkle like a thousand diamonds with the candle, or when brought to the sun. Between these clusters of mock diamonds, and sticking to them promiscuously, there are often lead ore, black jack, pyrites or sulphur, and spar, shot also into prismatic, cubic, or other figures, which grow one upon another, and are, as it were, piles upon one another. The whole inside of the cavern is sometimes most magnificently adorned with the most wildly grotesque figures, which grow upon and branch out of one another in a manner not to be described, and with all the gay and splendid colours of polished gold, of the rainbow, and of the peacock's tail, and all these blended together, and the masses reflecting all the beauty of such an assemblage of gaudy colours. But it may be remarked that these caverns are never so magnificent and glorious as when there is less or more of yellow copper ore, or of pyrites, or black jack, in them, as these ores are found to produce in hard veins the most beautiful colours in the world. Many eminent instances, in proof of this assertion, are to be seen in the lead mines at *Allenheads* and *Coal-Cleagh*, in Northumberland, and *Nenthead*, in Cumberland.

"Quartz does not rise in blocks (in this country) or large regular masses . . . . it being full of cracks so as to break into small irregular masses, with various sharp angles, and it is so hard as to waste the tools more than any other stone. Where quartz and quartzy spar prevail, the veins are hard to work, and it is no easy matter to separate the ore from the quartz in dressing, being so hard that it requires much labour to break the quartz with ore small enough; and it is also so heavy that it does not easily separate." *

The *Van* mine,† which has been one of the most productive lead mines in the British Isles, lies about 2½ miles north-north-west of Llanidloes, in Montgomeryshire. The lode is well described by Dr. C. Le Neve Foster, who loses no opportunity—afforded by his position as Inspector of Metalliferous Mines—of inquiring into the various phenomena which are constantly brought under his notice.

This vein is said to have been traced along the strike for a distance of 9 miles, but this is doubtful. The lode at the Van mine runs in a direction of about east 26° north (true), and dips south on an average about 74°, though sometimes the dip is not more than 67°. The width of the lode is generally several fathoms, and the portion producing ore is 48 feet wide. The filling of the fissure may be regarded as composed of three distinct parts on the south side, the *flucan*, or *soft lode*, which is a mass of clay and broken-up Slate, varying from 12 to 24 feet in width. It appears evident that this great fissure or gash was for a considerable period the channel of a deep torrent, and that during this flow the Slate rock was softened, broken down, and for some depth converted into clay. This is proved from the fact mentioned by Dr. Le Neve

* Westgarth Forster's "Treatise on a Section of the Strata," p. 219. 1821.

† Mr. T. F. Evans and Captain Williams both say that the name is derived from a neighbouring hill, "y, Fan"—that is, *the place*, or *the spot*. Captain Williams informed the author, when he visited the mine, that there existed, long previously to the discovery of the mineral treasures found in this hill, a traditionary feeling that it was a marked spot, upon which sooner or later a great mine was to exist. Whether this had its origin in some very early explorations or not could not be ascertained.

Foster that in the deeper parts of the mine the *flucan* diminishes in width, and at the bottom level is only a few inches thick. Or it may have been, that two parallel fissures were formed by the same mechanical disturbance, for one division—now called the *Bastard lode*—is a mass of Slate rock generally 4 or 5 fathoms wide between the flucan and the true lode. In the annexed woodcut (Fig. 96) A A represent the country, which is composed of Lower Silurian Slates, C is the clay or flucan lode, and D the Bastard lode, E being the true metalliferous lode. The Bastard lode is a mass of Slate rock, having on its south side the softened clay mass, probably Slate decomposed, and on the north the true fissure lode. This *lode* (?) is softer than the country, and is traversed by numerous strings of the sulphide of lead. Occasionally it is rich enough to pay for working, and in some *stopes* above the 90-fathom level the most productive part of this lode was found. The galena in the Bastard lode was foliated in its character, partaking much of the character of the potter's ore of Shropshire. Between this and the true lode a wall or division is generally found, frequently consisting of a yellow hornstone in which a little blende is found. The regular lode consists of masses of Slate traversed by veins of galena. These veins are sometimes mere strings, in other cases they become branches from 1 foot to 2 feet wide.

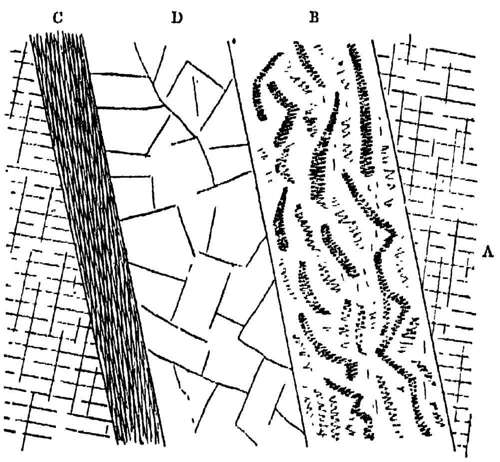

Fig. 96.—The Lode in the Van Mine.

With the galena there are considerable quantities of blende, with quartz, and some iron pyrites, marcasite and copper pyrites. Dr. Foster says: "In several specimens I noticed the succession, 1 quartz, 2 galena, 3 blende, 4 quartz; but I am not sure that this order always holds good." It appears upon a careful examination to vary considerably. This lode is a good example of a *brecciated* lode. It is made up of fragments of slate cemented by quartz, galena, and blende. The footwall of the regular lode is generally well marked, and *slickensides* are frequently met with, and these striated surfaces are often found in the joints of the lode itself. The fissure in which the lead lode of the Van mine is found is said to be very extensive, but the length of the ore ground varies with the depth, from 60 fathoms at the adit to more than 200 fathoms at the 90-fathom level, 150 fathoms being reckoned as the length of the very productive part of the shoot. A gas, said to be light carburetted hydrogen, is found, as Captain Williams informed us, at the adit level and in level below it when first the lode is tapped. The gas rushes out with the water with much noise, and appears to come from a greater depth. Occasionally this gas, mixing with the air, forms an explosive mixture (*fire damp*), and, although no serious accident has happened, the miners have been scorched by the flame and their hair singed. It is not easy to

account for the presence of carburetted hydrogen gas in such a lode as that found at the Van. Sulphuretted hydrogen might readily arise from the decomposition of the ores, combined with sulphur, and Dr. Foster says : "It is not improbable also that sulphuretted hydrogen is emitted. I smelt this gas very perceptibly in one part of the mine, and more strongly, I fancy, than would have been the case if there had been sulphuretted hydrogen formed by the decomposition of the potassic sulphide in the gunpowder smoke on meeting with water." Captain Williams gave many reasons in proof of the gas being light carburetted hydrogen, and he believed that it came, when relieved from pressure, from a considerable depth. It is possible that the lead lode, at some point not yet reached, passes through a bed of carboniferous shale, from which the gas may have been evolved. Occasionally small quantities of an explosive mixture have been found in the deep mines of Cornwall, but, in all cases, it has been traced to the decomposition of wood-work in damp parts of the mine.

Gossan—Earthy Brown Iron Ore.—This is found so frequently near the surface, especially, of copper lodes, and it is considered of so much importance by the miner, that a brief space must be devoted to its consideration. The largest proportion in the composition of mineral lodes is quartz, and generally near the surface this is full of hollows and drusey cavities, which are almost always filled in with this ochrey mass, termed by the miners *Gossan.*

Gossan almost invariably accompanies copper ore in the upper part of the vein. It is often found also in veins containing silver, and the mineral substances, called in Cornwall *scovan* and *capel*—which may generally be regarded as intimate admixtures of quartz and chloride (*Burr*).

When *gossans* contain metallic substances, they are tolerably hard, and their ferruginous matter is in colour almost a chocolate brown, but they often contain softer portions: for example, a friable quartz, locally termed *sugary spar*, and also felspar-clay, often called *prian* (*Henwood*).

For this substance there is no precise mineralogical name. It varies much in composition, and, as may be supposed,—since it is evidently the result of decomposition of the lode above which it rests,—partakes to a certain extent of the nature of the mineral veins. The miners in this country are guided in their opinions as to the probability of a lode proving rich, by the appearance of this ferruginous mass. "Keenly gossan," meaning *kindly* (promising), is referred to by them with much show of knowledge. In the German mines a similar deposit is noticed and termed by the miner *eisenhath*, or the *iron hat* of the vein. They have a proverb, "There is no lode so good as that which wears an iron hat."

De la Beche says: "It has been found that the percentage of cases is considerable where an iron-ochreous substance named 'gossan' prevails, and copper ore is connected with it, and it may be said that the instances are very rare where copper is found in fair quantity in a lode without gossan having been discovered on the 'back' or upper part of the lode. This gossan, which is generally mixed with quartz and other mineral substances, among which oxide of tin frequently occurs, differs much in general aspect, and the experienced eye of the miner readily detects that character which is most

indicative of a good copper lode, though it is one that can scarcely be expressed in writing." *

Gossan appears to be the result of the decomposition of the upper portion of a lode, exposed, as it will be, naturally, to the influences of atmospheric air and of water. If we consider that a copper lode consists, usually, of copper pyrites (a double sulphide of copper and iron), of iron pyrites (sulphide of iron), and other similar constituents, the first being especially liable to decomposition, we can readily account for the accumulation of masses of oxide of iron, containing, as well, the other minor constituents of the mineral lode in the exposed portions of the vein. "Veins commonly possess the same general appearance in valleys, as in the contiguous hills . . . in both situations the metalliferous veins are, usually, equally furnished with 'gossan' or other foreign matter overlying the ore." †

In lodes which contain *gossan* near the surface, there is generally a diminution of its ferruginous ingredients at greater depths. Where copper ores abound, the earthy black copper, at first, is mixed with the *gossan*, the proportion of the iron ore decreases, and that of the copper increases; whilst in those portions of the lodes which are unproductive, immediately beneath the *gossan*, the ferruginous particles are replaced by hard milk-white quartz (*Henwood*). These facts are confirmatory of the view expressed, that the *gossans* are entirely due to the decomposition of the yellow ore.

Nearly all the gossans contain silver. In the mineral district of the Tamar a considerable quantity of silver has been produced by veins of a gossany nature, chiefly in a finely disseminated state, and at no great depth from the surface. The first discovery of silver in Cornwall is reported to have been made at Wheal Mexico, in the Perran district. Dr. Berger says‡: "The vein which was formerly worked at Wheal Mexico in Cornwall, was in grauwacke Slate. The ore appeared to be mixed in a gossan in the form of insulated masses or nests; besides the native silver—muriate of silver or horn silver—*corneous ore* was also met with."

At *Herland* one of the *cross veins* yielded an abundance of silver, sometimes in the native state. In the shallower parts gossan accompanied it, the whole being distributed through a white crystalline quartz, with numerous *vughs* (cavities) which were often lined with capillary silver. A well-known metallurgical chemist, a few years since, obtained some twenty specimens of gossans, from the backs of some of the lodes in the mining districts of St. Agnes and of Perranzabula. These were assayed with much care, and from more than two-thirds of the samples weighable quantities of silver were obtained, and from two of the specimens traces of gold.

Many years since a silver refiner from Sheffield visited Cornwall, and his attention was directed to the gossans. He made some very careful examinations, and purchased a sufficient quantity to freight a ship to Liverpool, from which port it was conveyed to Sheffield by land. Notwithstanding the heavy cost for carriage, he realised several hundred pounds by the silver which he obtained.

* "Report of the Geology of Cornwall, Devon, and West Somerset." By Henry T. de la Beche, F.R.S. 1839.

† Robert Were Fox, "London and Edinburgh Philosophical Magazine," vol. i. p. 239. 1832.

‡ "Geological Transactions," vol. i. p. 171.

Mr. J. Carne informs us that many of the gossans are valuable for the tin which they contain. He says*: "An instance of the top of a copper lode having been taken away for the sake of the tin which it contained, occurs at Wheal Damsel and Wheal Spinster copper mines. The Granite walls of the lode are still visible at the surface and to the depth of three or four fathoms, having a space of about 4 feet between them. It is probable that, if the rubbish were taken away, the space would be found to extend to the depth of perhaps 10 fathoms, or as deep as the ancient miners could go without being obstructed by water. *From this space the fine gossan of the copper lode was wholly taken away, and the tin ore extracted from it.*

"*Gossan* has been returned for the sake of its tin, within the recollection of some of the oldest miners living, but at present the expense of extracting the small quantity of tin contained in *gossan* is so great in comparison of what it costs to obtain it from other sources, that I believe nothing is now done in that way."

It must be noticed that many rare and curious crystalline minerals occur where *gossan* is plentiful. Mr. W. J. Henwood gives a list of some 16 mines in which rare minerals have been found in the gossans. Lodes which afford no *gossan* were, he says, formerly called *scovan*-lodes,† and he adds, "I have often seen fine specimens of copper pyrites in gossan at Cœ-Mawr, near Dolgelly, in North Wales," proving that the formation is not confined to Cornwall.

Pseudomorphism—ψευδής, *false*; μορφή, *form*.—Without a short statement of the phenomena included under this term our subject would be incomplete. We have been discussing the question of the formation of gossan. This may be regarded as an example of the changes which occur in minerals to which this name has been given. The term is strictly applied to alterations in the forms of crystals, but some authorities apply it to changes in the beds of rocks, to which the term *metamorphism* is more correctly applied. Dana,‡ for example, says: "Thus all Serpentine, whether in mountain masses or the simple crystal, has been formed through a process of pseudomorphism, or, in more general language, of metamorphism. The same is true of other magnesian rocks, as steatite, talcose, and chloritic Slates. The crystalline rocks often offer examples of a similar change. The graphite of these rocks may be but a pseudomorph—or metamorph—after some vegetable product, and, as truly so, as the petrified wood of more recent times. Thus the subject of metamorphism, as it bears on all crystalline rocks, and that of pseudomorphism, are but branches of one system of phenomena; the chemistry is the same in both."

This definition of the term does not appear to be strictly correct. The change of pyrites, either of iron or of copper, into earthy red or brown iron ore, can scarcely be regarded as a false form. It is a case of chemical change. By the action of the atmosphere, the bisulphide of iron has parted with its sulphur, and the iron has become an oxide—the *gossan* of the miner. The change of felspar crystals into oxide of tin is a true case of pseudo-

* "Transactions of the Royal Geological Society of Cornwall," vol. iii. p. 41.

† Jars's "Voyages Métallurgiques," iii. p. 193; Pryce, "Mineral Cornubion," p. 90; Mr. Phillips, "Geological Transactions" (Old Series), vol. ii. p. 118.

‡ "System of Mineralogy," vol. i. By James D. Dana, A.M.

morphism. The felspar, by a natural process not quite understood, undergoes a process of disintegration, and for every particle of the felspar converted into *kaolin* (china-clay) and removed, a particle of oxide of tin is deposited. Thus eventually the mould left in the Granite—of the felspar crystal—is filled with the oxide of tin, which retains the true form of the felspar mould. As stated, the grains of tin—each one of which may be regarded as a crystal, more or less perfect—retain their form; but as each addition is made, crystal unites (agglutinates) to crystal, and the final result is a cast in oxide of tin of the original felspar crystal, made in a felspar mould. Crystals are obtainable from the Granite of Wheal Coates in St. Agnes, and also from one or two mines in St. Just, in every stage of change. Professor Bischof has the following misleading note*: "Some geologists hold that there is a third class of pseudomorphs, produced by a deposition of substances in cavities left in rocks by the solution of imbedded crystals. This process would be analogous to casting in a mould. There does not, however, appear to be any evidence in favour of this view, or any probability that a crystalline mineral introduced into such a cavity would assume the form of the cavity and not proper to itself."

Dana mentions petrified wood as an example of pseudomorphism. It is so; for every particle of wood removed from the tree, a particle of silica has taken its place, until the woody substance has entirely disappeared, and silica alone remains; the flinty mass retaining with great delicacy the true woody structure. Dana thinks that pseudomorphs should be classed under four grand heads—

1. *Pseudomorphs by alteration.*—Those formed by a gradual change of composition in a species; *e.g.* change of *augite* to *steatite*, or soapstone.

2. *Pseudomorphs by substitution.*—Those formed by the replacement of a mineral which has been removed, or is gradually undergoing removal; *e.g.* change of Felspar to oxide of tin—the petrifaction of wood.

3. *Pseudomorphs by incrustation.*—Those formed through the incrustation of a crystal, which may be subsequently dissolved away; often the cavity is afterwards filled by infiltration; *e.g.* change of fluor-spar to quartz.

Some interesting specimens of this order have been obtained, in considerable quantities, from the Virtuous Lady copper mine near Tavistock. Carbonate of iron had covered cubical crystals, probably of fluor-spar, which had been formed on bisulphide of copper, and had entirely disappeared, leaving cubical cavities, produced by the crust of the carbonate of iron. In these cavities, some of which were large, quartz and bisulphide of copper had crystallised, filling them up only in part. In this mine some remarkable pseudomorphs called "Ladies' Slippers" were also found.

Haidinger has described † many alterations depending upon gradual changes which take place in the interior of minerals while their external forms remain the same. Under the head of "parasitic formation of mineral species," he has noticed changes which have been produced on substances having the same composition, and on others which contain copper, iron, lead,

* "Elements of Chemical and Physical Geology," vol. i. p. 19. By Gustav Bischof, Ph.D. (Cavendish Society's Transactions.)

† "Transactions Royal Society of Edinburgh," vol. ix. p. 73.

manganese, barytes, antimony, and earthy minerals. He adduces many new compounds which have taken the form of the original crystals, apparently by gradually displacing their constituent parts. Haidinger states that "Professor Mitscherlich exposed crystals of hydrous protosulphate of iron, immersed in alcohol, to a degree of temperature equal to the boiling-point of that liquid. Decomposition ensued, though the external shape of the crystal remained unchanged. On being taken out of the liquid and broken, each of them was found hollow, and presented a *geode* of bright crystals deposited in the planes of the original ones. The crystals had the form of low eight-sided prisms, belonging to the prismatic system, and were proved by analysis to contain exactly half the quantity of water which is required in the mixture of the original species." * These may be included in—

4. *Pseudomorphs by paramorphism.*—Such as are formed when a mineral passes from one dimorphous state to another; *e.g.* change of aragonite to calcite.

These changes are not always distinguishable. In some cases a change may take place through *alteration* of the surface; and then, this process ceasing, the interior may be dissolved out, leaving a pseudomorph like one *of incrustation*, or a pseudomorph which appears to be the result of alteration explicable on chemical grounds, may be wholly due to substitution simply.

The term *paramorphous crystals* was first used by W. Stein, and adopted by Scheerer,† to designate certain pseudomorphs in which a change of molecular structure has taken place without alteration of external form or chemical constitution. As, the monoclinic crystals of fused sulphur, which gradually become opaque, and are then found to be made up of crystalline particles having the trimetric form of sulphur crystallised from fusion at low temperatures or of aragonite altered internally to calc-spar and of iron pyrites altered internally to marcasite.‡

Dana gives a very long list of substances, including the elementary bodies in which these phenomena occur. *Native copper,* which imitates red copper and aragonite. *Native antimony,* which imitates Valentinite; and of *Graphite,* which imitates pyrites.

"These examples of pseudomorphism," Dana says, "should be understood as cases not simply of alteration of crystals; but, in many instances, of changes in beds of rocks. Thus all Serpentine—as already stated—whether in mountain masses or in simple crystals, has been formed through a process of pseudomorphism." . . . . Metamorphism, as it bears on crystalline rocks, appears to be the result of decomposition, usually produced by heat, as by the intrusion of masses of igneous rock; and is, certainly, notwithstanding the dictum of Dana, in several respects different from pseudomorphism.

We have already stated that lodes containing copper pyrites are often changed above to red or black copper ore: a change which is, as we have shown, produced by the slightest alteration in the electrical condition. Impure *chrysocolla* (silicate of the oxide of copper), or malachite. The former

* "Transactions Royal Society of Edinburgh," vol. xi. p. 79.

† "Journal Pract. Chemie," lvii. p. 60.

‡ See Scheerer, article Paramorphose, in the "Handwörterbach der Chemie," vol. vi. p. 53.

is frequently found investing the latter. Mixed with the *gossan* we find disseminated all the sulphides, arseniates, &c., that are associated with the copper ores of the lodes. The *erubescite* (purple copper ore) of the upper part of a copper lode is supposed to be a comparatively modern product, arising from the alteration of vitreous copper. Phosphates, and arseniates of copper, lead, &c., carbonates and sulphates, are among the surface species, or those that occupy the upper part of metallic lodes. They are the result of alterations within the depths to which atmospheric agencies penetrate.

We have already noticed the experiments of the elder Becquerel, which established conclusively the influence of weak electrical current in producing chemical change. Without doubt the changes we have been describing are due to the electro-chemical power which is produced whenever a compound body, such as a mineral ore, undergoes decomposition. A simple experiment will prove this most satisfactorily. Into a glass jar we place a solution of muriate of barytes, B, and pour carefully down the sides of the vessel some pure water, so that it float on the barytic solution as shown at A. A piece of yellow copper ore, which is a compound of sulphide of iron and sulphide of copper, is suspended by a string, and hung from a bar placed across the jar, so that one half of the ore is in the solution of muriate of barytes, and the other half in the water. If this is allowed to stand, it will, after a short time, be seen that the half of the yellow copper ore which is in the barytes solution will begin to change colour, and gradually a fine white cloud will form around it, and a fine powder fall through the fluid to the bottom of the vessel. This will be sulphate of barytes. The sulphur of the ore will be converted into sulphuric acid, and this will combine with the barytes forming the insoluble sulphate. As this process goes on, the copper ore will become iridescent, and eventually be changed into grey copper ore, sulphide of copper, and a film of oxide of iron will gather on the sides of the glass at the line of junction between the two fluids, thus representing precisely the conditions under which gossans are formed on the backs of copper lodes. If the experiment is carried out with proper precautions, and, after a time, when the changes have gone on for a few weeks, if the ore be weighed, it will be found to have lost weight, and loss will be found to be the sulphur of the sulphuric acid combined with the barytes, and the iron in the oxide of iron film formed upon the glass.

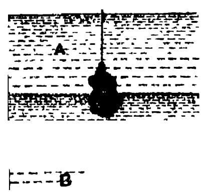

Fig. 97.

"The causes of change," says Bischof,* "are the simplest and most universal operations about us. (1.) The solvent power of ordinary waters, cold or hot, or of steam. (2.) The reaction, according to chemical principles, of the ingredient dissolved in those waters, or in mineral or sea waters, heated or at the ordinary temperature. (3.) The progress of gradual oxydation to which some substances are liable, and the reaction of substances thus formed on the ingredients at hand, aided or promoted by electrical currents or heat. (4.) The action of exhaling gases from the earth, with or without volcanic action." The Professors Rogers subjected a large number

* Gustav Bischof, "Chemical and Physical Geology."

of minerals in powder to the action of water containing carbonic acid by filtration. Some gave evidence, at once, of the solution of the substance experimented on. Pure water gave with many of them a like result, but more slowly. The result obtained, according to Bischof, illustrates two important facts:—

1. That ordinary waters upon and through the Earth's surface are constantly active in dissolving and decomposing minerals and rocks, and even the species reputed indestructible are thus acted on.

2. That the waters are thus furnishing themselves with chemical agents for effecting other changes.

A few more facts connected with the changes in the minerals, which we have been considering, will be of interest.

Mr. R. W. Fox observed the yellow sulphide of copper in the form of crystals of carbonate of iron, which it must have gradually displaced, sulphide of lead—in six-sided prisms—termed blue lead, having superseded the phosphate of that metal, pseudo-hornstone projecting through the centre of a crystal of octohedral fluor.*

M. Becquerel states that M. Darect left a plate of steel during eight years in a case, at the Mint of Paris, in contact at one of its ends with a solution of nitrate of silver, which reached it very slowly from a fissure in the vessels containing it. One half of this steel plate was entirely changed into very pure silver, offering a resisting mass without the least trace of iron. The volume of the plate of silver was visibly the same as that of the plate of steel. Becquerel thinks this singular effect must have been produced by actions *analogous* to those which have converted antique bronze coins into the protoxide of copper. This is not pseudomorphism.

The production of pseudomorphs appears to depend upon an incrustation of the original crystal, or some other accidental circumstance. The number of instances in which the form of the original mineral is destroyed, and the product of the change appears in its own crystalline form, is by no means unimportant, and it would be still more important if, after the completion of the change, those characteristics were not wanting which might enable us to decide whether this or that mineral had furnished the material.

The *association of minerals* in rocks has an intimate bearing on the question of their origin. Associated minerals may obviously have been either contemporaneously or successively formed. If the former, the species were alike in this general phenomena attending their origin; if the latter, there may still be many circumstances in common arising from their condition in the same rocks, or their dependence on the same system of causes, or from the earlier contributing more or less to the material of the latter; or, again, they may have no relation except that of relative position (*Dana*). Breithaupt,† Bischof, Delesse, and others have paid great attention to this subject, and have given groups of associated species, from which the following few examples are quoted:—

Serpentine.—Diallage, hornblende, pyroxine, pyroselerite, chromic iron, brucite, hydromagnesite, aragonite, dolomite, emerald nickel, pyrope.

* "Reports of the Royal Cornwall Polytechnic Society," 1836.

† "Paragenesis of Minerals."

Tin Ore.—Wolfram and scheelite, molybdenite, magnetic pyrites, tourmaline, fluor-spar, beryl, topaz, apatite, pyrrchlore, native bismuth.

Galena.—Blende, copper pyrites, calcite, heavy spar, spathic iron, quartz, fluor-spar, pyrites, tetrahedrite.

Copper glance.—Grubuscite, native copper, malachite, red copper, pyrites, copper, galena, blende, iron pyrites.

Cobaltine.—Cobalt and nickel ores, mispickel, magnetic pyrites, axinite, copper pyrites, limonite, &c. &c.

As this bears directly on the appearance of metallic minerals in certain rocks—as tin and copper in Clay-Slate, and lead in Limestone—the reader should consult again the pages devoted to what has been termed "the rock conditions" in relation to mineral veins.

"I consider," says Bischof, "that the entire removal of fluor and calc spar from a whole series of veins, and the introduction of an equal quantity of quartz in their place, is a matter of vast importance. And how do we know that this has actually taken place? Because we find quartz in the form of fluor and calc spar. Is it not to be inferred from this fact that far more stupendous displacements have taken place where the processes have continued longer? To what enormous spaces of time we come when we reflect upon the periods during which the fluor and calc spar were introduced into those fissures, and then the periods during which these minerals were again removed by water, and quartz substituted in its place."

The following passage, abstracted from Professor Bunsen, forms a peculiarly appropriate conclusion to this chapter. "Pseudomorphs furnish us with a kind of knowledge which we have no opportunity of deriving from any other source. It will scarcely ever be possible to convert augite, olivine, or hornblende, &c., into Serpentine in our laboratories. But when we find Serpentine in the form of those minerals, this fact is sufficient evidence that such conversion can take place; and if in any given instance there are geognostic reasons for the opinion that one or other of these minerals, or even several together, have furnished the materials for the formation of Serpentine, there is a high degree of probability that such a change has actually taken place."

In considering the operations of Nature, we should never forget that TIME is an all-important element in her works, and that subtile forces are ever slowly and silently producing the grand phenomena of creation.

BRITISH MINING.

BOOK III.

PRACTICAL MINING.

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BRITISH MINING.

BOOK III.

PRACTICAL MINING.

CHAPTER I.

DISCOVERY OF MINERAL LODES, AND THE OPENING OF MINES.

IN the preceding pages the historical sketch of mining will have made careful readers acquainted with the steps by which the discovery of mines has been made. The methods adopted, to render our subterranean explorations of value, by disclosing the hidden treasures of the Earth's crust, will form the subject of the present chapter.

Experience has instructed us,—often at very considerable cost,—in the peculiarities which mark a mineral district. We know now that there are certain localities, within the area of which we may reasonably hope to find mineral wealth, and that there are other well-defined regions which we know to be absolutely sterile. These facts have been already explained, therefore it is not necessary to repeat the explanations here. If we examine Cornwall or Cumberland, Devonshire or Derbyshire, or Durham, Wales, or Westmoreland, we shall find that over every square mile, within which there was the remotest probability that mineral ores might exist, the ancient miners have left traces of their unwearying industry. We are, therefore, instructed, by the labours of our forefathers, where to search for treasure, and they have indicated to us the spots where, in all probability, any exploration would end in disappointment. The successes of our ancestors, and the failures of the "old men"—as the ancient miners were called—should be guides and guards to all modern explorers.

It has been shown that tin is to be found, as a rule, only in the Clay-Slate rocks, which exhibit a peculiar colour and character, or in a coarse Granite which is broadly distinguished from such as would be selected for a building stone. We know that Elvans, the Toadstone, and other rocks, which are evidently of igneous origin, have a very marked influence on the occurrence of metallic ores. Copper ores certainly show a tendency to accumulate in fissures, which have been prepared to receive them, in the older rocks and near the junction of dissimilar formations. Lead ore is found in geological formations of widely different ages, but it more especially appears to show an affinity for Limestone.

Again, we know that the direction of fissures indicates that some influence is exerted on the deposits, as they take a bearing which has some relation to the lines of magnetic force. This is a point on which we have numerous indications, but the question requires an examination which has not yet been given to it. For one or two varieties of ore, an easterly and westerly strike appears to be the most favourable; but we have examples, which are especially instructive, showing that very wide deviations must be accepted, as being within the limits of the production of profitable mineral veins.

Notwithstanding the attention which has been directed to the laws regulating the deposits of metallic ores, it must be confessed that we are still without any certain guide to the presence of lodes beneath the surface of the Earth.

"By cutting the ground
The metal is found,"

continues to be almost as true now as it was two centuries since, and the miners' phrase—

"Where it is—there it is,"

remains a truism, notwithstanding our boasted applications of science. This is a very humiliating confession to make in these days, when every inducement is given, by instruction in mining schools and science classes; but as even the discovery of mines remains a mere matter of guessing, it is not possible to give any rules which can be regarded as reliable. Dr. Borlase,* generally a very clear observer, after he has described the occurrence of tin in streams, writes: "Tin ore is also found dispersed in the body of the stone, dispersed in spots and bunches, where there appears no fissure, lode, floor, or rectangular intersection, as in other *strata*. These spots are sometimes so large and numerous when in Granite (as in Trevegean, in St. Just) that they will require the labour of the miner, though he is generally obliged to blast the rock, and afterwards break it with sledges, in order to get at the tin. If these spots be in the blue Elvan stones (as we find them near the Land's End), *no iron will pierce the stone, neither can it be blasted with gunpowder.*" This is quoted as an illustration of the imperfect knowledge which prevailed at the time this was written. After giving several accounts of the modes of occurrence of tin, Dr. Borlase continues:—

"Having now considered the several states and situations in which tin is found, it must be observed that tin does not appear so frequently in either, or all of them together; but that people are perpetually searching after more, and endeavouring to make fresh discoveries. To say nothing of dreams and fires by night, motives equally illusive, though prevalent still among the vulgar, few of the Cornish have ever heard of the *virgula divinatoria* and its virtue in discovering lodes. Having already given a full description of the divining-rod and its uses, it is only necessary in this place to direct attention to the very recent period at which the use of it was but little known. Neither are they often (perhaps not so often as they should be) directed by the taste and colour of waters. The run of a lode is sometimes discovered by the barrenness of the surface and want or weakness of grass in a particular furrow; thus in the tenement of Trevethick, in St. Agnes parish, though the field is cultivated equally in every

* "Natural History of Cornwall," 1758.

part, you can distinguish the course of the lode by the unequal growth of the grass. This must be owing to one of two causes: either there is so much mineral salt below the soil, that the roots of the plants are parched, or the earth and substance of the lode is so porous that all the nourishment of the manure is dissipated and sinks below, instead of being raised into the plants. Much surer indications of treasure are often found in cliffs and caverns, where the lodes, laid bare for some fathoms in depth, may easily be examined at several stages. Some of the curious will think, that discoveries may be made by observing the position and alteration of the several *strata* as we descend into our mines; but there is no uniformity to be assumed in the strata of one hill and those of another half a mile off . . . . and therefore no judgment can be formed from the situation of the *strata* in one place, where, how, or in what condition lodes are to be found in another place." After mentioning the driving of adits, Dr. Borlase proceeds:—

"It is much easier and less expensive, and therefore most common, to trace lodes by the *scattered* fragments of them called *shodes*, and as this is a kind of science which few tinners understand, but those who have chiefly applied themselves to these researches, it will require more particular notice." Before continuing this quotation it will be more satisfactory to give Borlase's own definition of a *shode* stone. Referring to the *broil, or bryle of a lode*, that is, the disintegrated portions of a mineral vein, found at, or near, the surface. From this, Dr. Borlase supposes loose stones have been removed. He was not sufficiently acquainted with geology to be aware of the vast quantity of matter which has been removed from the surface of the Earth, and the consequent destruction of the lodes themselves. However, supposing lode-stones to have been derived from the *broil*, he continues:—

"The smaller stones are carried farthest; on the contrary, the largest stones are nearest the lode. The smaller are also nearer to the surface of the ground; but the larger ones deeper and still deeper as you approach the lode till the last are found contiguous to the lode itself. The farther distant these stones are from the lode the fewer they are in number; but they multiply as you come nearer, and are always in greatest plenty next the lode. These stones are known from all others by their being of a different colour and structure from the *shelf-rubble* and other common stones of the ground where they lie; but more particularly their angles being worn off, and the farther distant they are from the lode the smoother they are, and the nearer, the less are their angles blunted. In Cornwall we call these dispersed parts of the broil *shodes*, perhaps from the Teutonic word *shutten*, to pour forth." The searching for these stones is called *shodeing*. "If the shode is found in the vegetable soil it gives no evidence of any lodes being nigh; but if in the *fast* (that is, the rubble or clay never moved since the flood) it is taken as a never failing proof that it came from a lode farther up the hill. As soon as the shode is found impregnated with tin, to find the lode it came from is the next care. The process consists in digging pits at a proper distance, depth, and in proper direction, and judiciously regulating their advances to the lodes according as the properties of the shodes direct. First, the run of the lodes being known to be in the hill above the shode, the several declivities below the hill, and where water may be supposed to have run with greatest force, must be considered, and there, at right angles to

such force must the shafts be placed crossing such declivities." This process is called in the Cornish tongue *costeaning*, from *cothas-stean*, *i.e.* fallen or dropped tin, and the pits or shafts sunk are *costeaning pits or shafts*.

W. Pryce, who wrote in 1778,* devotes many pages to the consideration of the divining-rod, of which he says: "The merit of the essay on the *virgula divinatoria* is due to Mr. William Cookworthy of Plymouth,† and though the virtues of the rod may not be easily allowed by the incredulous, yet, for my own part, I want no further evidence of its properties than I have already obtained to fix my opinion of its virtues." Although a conscientious believer in the virtues of the divining-rod, Pryce was a remarkably clear-headed man and a careful observer. He says, with much truth :—

"The principal investigation and discovery of mines depend upon a peculiar sagacity, or acquired habit, of judging from particular signs, that metallic matters are contained in certain parts of the Earth not far below the surface. But as ignorance and credulity are the portions of the illiterate, we have people constantly in search for tin, where our dreaming geniuses direct them to follow after the images of wild fancy; consequently, we have a *Huel Dream* in every mining parish, which raises and disappoints by turns the sanguine hopes of the credulous adventurers."

All this is as strictly true in 1883 as it was when Pryce wrote. He also says: "Mines have often been discovered by accident, as in the sea cliffs, among broken craggy rocks, or by the washing of the tides or floods; likewise by irruptions and torrents of water issuing out of hills and mountains, and sometimes by the wearing of high roads. Another way of finding veins, which we have heard of from those whose veracity we are unwilling to question, is by igneous appearances, or fiery coruscations. The tinners generally compare these effluvia to blazing stars, or other whimsical likenesses, as their fears or hopes suggest, and search with uncommon eagerness the ground which these jack-o'-lanthorns have appeared over and pointed out."

Pryce evidently doubted the truth of these luminous appearances. These forms of *ignis-fatuus* have been so often vouched for by reliable authorities that there appears to be no reason why phosphuretted, or potassiuretted hydrogen, should not be formed in marshy places, and both of these gases are spontaneously inflammable. At Swanpool, near Falmouth, such meteors are said to have been seen. The conditions at this place are, a small lake separated from the sea by a bar of sand, and beneath the lake a large lode of a curiously composite character which has been worked on. It has been stated by authorities—who could scarcely be doubted—that, under peculiar conditions of the atmosphere, the ordinary morass meteors have been seen flitting over the lake. The same kind of phenomena have been reported from other mines, but no evidence has been so precise as that relating to the Swanpool mine.

Meteoric appearances of another kind were reported as not unusual at the United mines when working. A large lode in one part of the sett is crossed by a caunter lode, and both have produced ores, but different in kind. One of the principal managers of this mine stated that he has often seen, in the early morning, two banks of cloud, or vapour, floating along

* "Mineralogia Cornubiensis."

† The discoverer of China-Clay, and originator of the manufacture of Plymouth china.

lines run in the same direction as these lodes. These banks of thin fog observe most strictly the line of the lode, and of the caunter, and they remained until the sun or the wind dispersed the vapour.

Pryce, after referring to the indications given by springs of the presence of copper, which may be detected by a piece of bright iron, or by a piece of tallow, says: "The iron in one case becomes coated with a copper film, and the tallow in the other is tinged of a green colour." He then devotes some pages to the virtues of the divining-rod, discoursing with much apparent learning on the philosophy of "the moving corpuscles," and "the conditions of the medium in which they move." Even in the present day many experienced miners,—and, in general, thoughtful men,—argue on the possibility of the action of some electrical force, or of some occult power, in obedience to which the rod bends to the Earth. The influence of the divining-rod is analogous to that of a turning-table, or of a whirling hat. Without human aid neither the one nor the other exhibits any power to move; therefore, the only safe conclusion is to regard the operator as the instrument of motion, and the movement as the result of what has well been called "a fixedness of idea," which, in its influence, may be regarded as one of the many psychological phenomena which yet require elucidation.

We have quoted Borlase on the matter of shodeing; a few notes from Pryce may with advantage be added. The following paragraphs are therefore abstracted from Pryce's "Mineralogia": "Henckell and Rösler say, that Mundick shode is very common, and that Wolfram, Granite and iron corns, nay quicksilver, are found in *shode* and stream, all of which Henckell says, were washed or torn away from their veins by the violence of the Noachian Deluge." Copper and lead shodes are very seldom met with; their "*bryles* being chiefly composed of 'tender unmetallic gossan,' which is not mineralised into copper ore at the *bryle*."

Obscured by the quaint language in which it is written, the following statement by Pryce covers a considerable amount of truth: "Almost every lode has a peculiar coloured earth or *grewt* (grit) about it; which is also sometimes found with the shode, and that in greater quantity, the nearer the shode lies to the lode; beyond which that peculiar *grewt* is seldom found with the shode. A valley may happen to lie at the foot of three several hills, and then they may find several deads *grewt*, or earth moved by the waters of the deluge, but not contiguous to the lode, with as many different shodes in the middle of each. This is also termed the *run of the country*; and here the knowledge of the *cast of the country*, or each hill in respect of its *grewt*, will be very necessary for the further tracing them, one after the other, as they lie in order."

"When the miners find a good stone of ore or *shode-stone* in the side or bottom of a hill, they first of all observe the situation of the neighbouring ground, and consider whence the deluge could most probably roll that stone down from the hill, and at the same time they form a supposition on which point of the compass the lode takes its course, for if the shode be tin or copper ore, or promising for either, they conclude that the lode runs nearly east and west, but if it is a shode of lead ore, they have equal reason to conclude that the vein goes north and south."

The above refers especially to the mineral district of South-western

England; but, with very slight differences, it applies equally to the mines of Mid-England and the Northern counties. As an example, Westgarth Forster,* in his chapter "On the Discovery of Mines," writes:—

"The peculiar signs of a latent metallic vein seem deducible to general heads, such as—

"1. The finding of pieces of ore on the surface of the ground—(Shode stones).

"2. The discovery of certain mineral waters.

"3. The finding of veinstone or rider.

"4. The finding of metallic sands.

"5. The discolouration of the trees or grasses in particular situations.

"6. The ascension of warm exhalations and the like, all of which are so many encouragements for making stricter search near the places where such symptoms appear. But when no *evident mark* of a mine appears externally, the skilful mineralist sinks or drives into the earth in such places as, from some analogy of knowledge gained by experience, or by observing the situation, course, or nature of other mines, he judges may contain metallic ores. When the mineralist has reason to suppose that certain veins bear towards any particular spot, the most effectual way of proving their existence is by driving an adit or level from the lowest ground *across the bearing* of the veins, by which means there is a certainty of cutting all the veins within the limit of his level."

Most lodes come to the surface of the rock in which they are enclosed; but this surface may be covered to some depth with drift deposits, or buried up beneath vegetable mould. This has of course to be removed or sunk through, and the "*shelf*," or surface of the rock, is carefully cleared, and broken into for the purpose of exposing the lode. It is important in all cases in "*prospecting*" for lodes—as the process of searching is called—to make ourselves well acquainted with the bearing of the mineral lodes in the district. Although lodes may, and do, vary in their relations to the magnetic meridian, they usually observe some relation to each other. Reference to the map, or to the plans, which have been given, will show this.

In all plans the bearing of the lodes becomes a point of considerable importance. It is easy to determine true north, by observing the shadow cast by a rod, fixed vertically in the earth, at noon; and by observing a compass-needle, it will be found that the magnetic north and south will deviate from the line of true north. On all plans the magnetic north should be carefully expressed, and the amount of declination (variation of the magnetic-needle) correctly noted at the date of the survey.

In England the bearing of lodes is referred to the points of the compass, as being so many degrees from the true north. The magnetic north is a variable point. At present (1883) time the variation of the compass at Greenwich is 18° 15′ west. Therefore to find the true north, in or near London, by means of a magnetic-needle, the compass must be so placed that the north end of the needle points 18° 15′ west; the north and south lines of the dial then will be in the true meridian. The declination alters according to the position of the place. In Dorsetshire and in Yorkshire it will be 19° 15′; in Devon and Cornwall and in Durham, 20° 15′, and so on.

* "A Treatise of a Section of the Strata," &c. By Westgarth Forster.

In Germany and some other countries the old system prevails of referring the bearing to a circle divided into hours; thus, a lode will be said to strike three, or to run from a certain point towards midnight, and so on. In the hilly districts of Yorkshire, and the Northern counties generally, the miners talk of a vein dipping towards the two or three o'clock sun.

It has been noticed that most lodes appear at the surface. The appearance of a lode at the surface may give but a very slight indication, yet it is rare indeed that some signs are not observable. Ore may not be found, but the fissure, however slightly it may be, filled with clay or gossan, is always discovered by a careful searcher.

In Cornwall no copper ore of any value has been raised till 30 or 40 fathoms in depth has been reached. The great mine of Preibram in Saxony had to be sunk 20 or 30 fathoms before it became productive; although the lode was large at the surface, but filled only by soft brown iron ore (*Smyth*).

In searching for mineral veins we have to determine the course of outcrop of some lode already known. It is necessary to take the average direction of the lode for some hundreds of fathoms in order to avoid errors, which may arise from the inequality of the ground. It will be evident that a lode, in passing through a valley, will be carried down the valley in the direction of the dip. Many miners believe that if a lode is heaved by a cross course, it is sure to come back again into the original line; but this is exceedingly doubtful.

In many parts of the world the lodes stand above the ground as distinct ridges. This is especially the case with the quartz reefs of gold-producing districts. In this country this is very seldom seen; sometimes a depression of the ground may reveal the position of the back of a lode. On the Moors of Yorkshire, and in Flintshire and Cardiganshire and other districts, such depressions often indicate the position of a mineral vein.

In the Moorland districts of the North of England, the miners have a process, called by them *hushing*, which they frequently use in searching for lodes. Their method is, first, to construct a pond and accumulate as large a quantity of water as possible. When sufficient water is collected, the wall of the pond is cut, and it is allowed to rush suddenly down towards a stream, tearing up the soil as it goes. This process of washing serves the purpose of cleaning the rock for examination; the indications of lead, if it exists, are obtained, and occasionally large masses of lead ore have been discovered by the process. The practice of *hushing* is wasteful, as a large quantity of valuable soil is often carried away and entirely lost.

HAND BORING.—The next process to be described is that of boring holes in the earth, which is carried out extensively in searching for minerals deposited in beds, but in the search for unstratified deposits the process is not, in all cases, of so much importance. Still, occasionally, conditions present themselves which render it convenient to use the most simple form of *borers* to pierce the soil, or deposits of sand and gravel, and even to penetrate the upper and always softer, parts of the rock, for the purpose of ascertaining if any ores of value exist beneath. For this purpose a very simple kind of apparatus is used. A general form will be that of a cylinder with a cutting edge round the bottom, and a slit up one side, very much like a gimlet. These tools are worked by a handle fixed to the tool, or by a bar of wood passed through an eye in the handle of the tool. If the boring is required to go deeper than

can conveniently be carried out by the hands of one or two men, unaided by mechanical appliances, it is usual to adopt the following method :—

The surface arrangements are shown by Fig. 98. In ordinary practice a well is first sunk of such a depth that the boring apparatus can be fixed in it ; and thus, a stage raised from the surface of the ground is dispensed with. A stout plank floor, well braced together with boards nailed transversely, and resting on putlocks, forms the stage. In the centre of the floor is a square hole, through which the boring-rods pass. The plant required consists of a spring-pole A, to assist in giving the necessary motion to the rods when at work, the three legs with pulley blocks, chain, and roller or windlass for drawing or lowering the rods, and the several lengths of rods required, with various chisels, pumps, &c.

Boring is commenced by digging a small pit about 6 feet deep; over this is erected three legs, pulley, &c. Sometimes a few feet of iron tubing is inserted for the purpose of protecting the sides of the borehole.

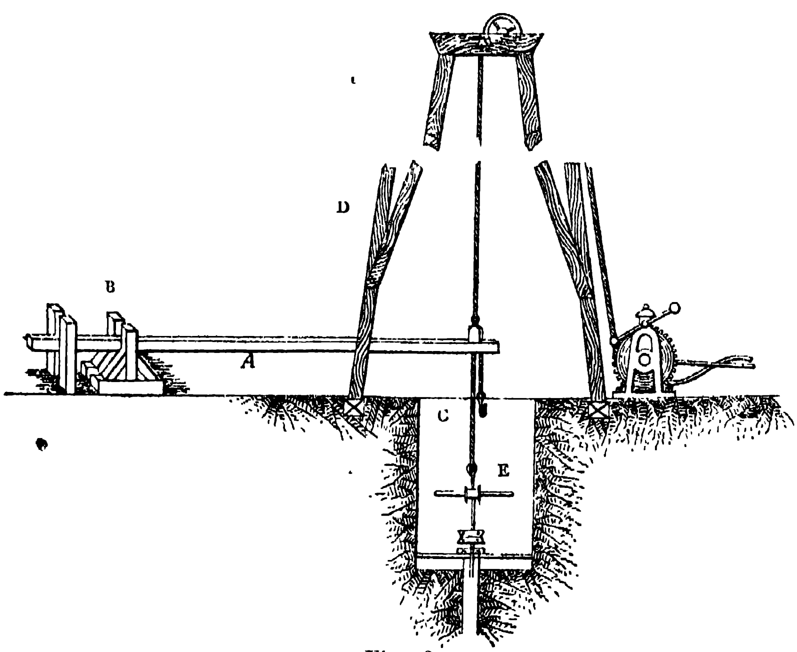

Fig. 98.

The boring-rods are from 10 to 20 feet long. First the chisel is inserted, then, as the work progresses, the rods are added. At the top of the rods are two handles placed at right angles to each other, by means of which the rods are worked up and down, at the same time altering the position of the chisel by a circular motion. As the depth increases, the men at the cross-bar or handles are assisted by means of a lever, A, at the surface, one end being firmly fixed in the ground between two posts, B, the other being allowed to pass over the hole. From the end of this pole the bore-rods are attached by means of chains, C, thus every time the borer strikes the chisel, the lever enables them to lift the rods high enough to give the necessary impetus to them for the next blow. The chisel is occasionally withdrawn, and a long bucket, with a hinged valve at the bottom opening upwards, is attached to the rods and lowered into the hole. The borer presses this down upon the material, broken up by the chisel, the débris becomes enclosed in the bucket, and it is drawn to the surface.

CHAPTER II.

PRACTICAL OPERATIONS FOR THE EXTRACTION OF METALLIFEROUS ORES.

THE use of the borer for the discovery of mineral deposits has been noticed in the previous chapter. It is, however, frequently desirable to employ the hand-boring machine in subterranean operations, and for this purpose the machine illustrated—Fig. 98—may be used. The various parts of the borer for underground work are of the same description as those used in the vertical machine, only they may be more lightly made. The rods are drawn out of the hole by the rope, the weight, which hangs in a small pit suspended by the rope, being raised at the same time. The rope is then slipped, and the falling weight drives the rods in the hole again. The rods are kept steady and horizontal by being caused to run over a small roller fixed on the frame, and also by moving a slide block adjusted by a screw and nut. After using the chisel for some time, the rods are withdrawn, and the pump, or scourer, introduced to clear away the débris, the other work being carried on as with ordinary vertical hand-boring.

It proves convenient in this place to consider the application of boring machinery in mining operations in its more advanced form. The simple arrangements already described may prove exceedingly useful in many places and under very varied circumstances. For example, it is often necessary, when advancing towards old workings, or the supposed position of old workings, known to be filled by water, to penetrate the rock in advance of the workings by bore-holes, and thus tap the source of danger. The same advantage is to be made available when large accumulations of carbonic acid or other gases are suspected. We have now, however, to enter on the consideration of rock-boring machinery in all its more important bearing on mining.

ROCK-BORING MACHINERY.—A few years only have elapsed since rock-boring machines were rendered successful in subterranean operations. At this time their application extends to most of the mining centres throughout the globe. In years to come this class of machinery, mitigating the miner's toil and aiding the object of his research, will occupy yet a more distinctive and important position. There is now no difficulty in applying ordinary boring-machines to wide stopes, for the purpose of extracting the ore, to rising and sinking on the lode, to sinking shafts in the country rock, and to all the varied purposes of mining.

In connection with the mechanical boring of shot-holes and removal of the ground, the miner has fortunately been aided by new explosives of unsurpassed strength. The result has been that, under the observance of a skilful and judicious system of working, a rate of progress in sinking shafts and

driving levels has been obtained, which is of the most beneficial character. To attain a quick rate of speed it is indispensably necessary to have recourse to good boring machinery, strong explosives, quick charging and blasting the shot-holes, and means for effecting the rapid removal of the stuff. Hindrances must be anticipated and avoided, and every facility established for executing each division of the work quickly.

In order to treat the subject of rock-boring machinery with some degree of clearness, reference will be made to the following heads :—

(*a*) Compressed air.
(*b*) Engines and compressors.
(*c*) Receivers and air pipes.
(*d*) Railways.
(*e*) Boring machines, stands, and frames.
(*f*) Rock-boring machines.
(*g*) Boring tools or bits.
(*h*) Water and ventilating apparatus.
(*i*) Explosives.
(*k*) Electric blasting.
(*l*) Driving levels and sinking shafts.

(*a*) *Compressed Air.*—The only pressure fluid suitable for driving boring-machines in close levels and shafts is that of compressed air.

The loss of initial power in effecting the compression of air is considerable, this loss increasing with increase of compression.

When steam machinery is employed the loss may be apportioned thus :—

1. Loss of work in the form of heat radiating from the boiler and engine.

2. Loss of work in overcoming the *vis inertia* of the machinery and friction induced in the moving parts of the engine and compressor.

3. Loss of work in neutralising the expansive effects of the heat occurring in the compression of air.

In the use of compressed air, after it has been forced into the receiver, other losses occur, viz. :—

4. From the friction of the air in the pipes employed for conveying the air to the boring-machines, this loss *decreasing* with *increase* in the diameter of the pipes.

5. In changing the movement of the boring-piston, which must necessarily run at a high velocity.

At the Blanzy Collieries, Montceau-les-Mines, France, considerable attention has been given to the subject of compressing air with the view of ascertaining the loss of power between the boiler and the boring-machines. At that place two kinds of compressors are employed—one a *Sommeiller*, in which the speed is slow, the valves large, the air compressed in contact with water which fills the clearance spaces, and delivers the contents of the stroke into the receiver; the other a *Blanzy* compressor, in which the piston speed is comparatively high, the cylinder surrounded by a water-jacket, and the cylinder-covers fitted with spray jets in connection with pumps by which water is forced into the cylinder during the compression of the air. M. Gralliot, the mechanical engineer to the establishment, selected the former compressor for trial, and after a series of exhaustive experiments ascertained in general terms that the work charged into the receiver in the form of compressed air represented from 35 to 45 per cent. of the work due to the steam within the boiler, while the work obtained through the medium of boring-machines was only 20 to 25 per cent. of the boiler work. It therefore follows that from *four* to *five* horse-power is required to afford *one effective*

horse-power in the boring-machines, and that the loss in transmitting compressed air from the receiver to the machines, and in changing the movements of the piston and its accessories, is from 15 to 20 per cent. of the power generated within the boiler. In other words, the *power* within the boiler is disposed of as follows :—

Loss, in transmission from boiler to engine, and overcoming resistances in engine and compressor	0·65	0·55
Loss, in passing from receiver through transmission pipes, and in changing the movements of the piston and its accessories	0·15	0·20
Effective power obtained in boring-machines	0·20	0·25
Total	1·00	1·00

The table confirming these general results, compiled by M. Gralliot, is subjoined, the figures being mostly according to the French metric system :—

Pressure per square inch	Lbs.	62½	35½	63¼
Revolutions of engine per minute . . .		10-11	10-11	13·15
Water injected into compressing cylinder . . .	Litre	·560	·560	·560
Temperature of water injected	Morn 71°	Fahr., Even.	89° Fahr.	
Work due to the steam used in steam-engines .	Kilos.	4361·60	3234·80	4460·00
Work absorbed by compressors	,,	3620·88	2575·44	4029·00
Work absorbed by the friction of the machinery .	,,	740·72	659·36	431·00
Co-efficient of the useful effect of the steam . .	,,	·83	·80	·90
Work absorbed by compressor, divided as follows :—				
Work absorbed in compression of air		1571·46	963·40	1655·64
,, in expelling air .		422·60	271·76	788·40
,, in expelling water		25·46	13·75	25·45
,, stored in receiver .		1601·37	1320·54	1560·11
Work lost by the heating of the air		393·76	210·23	797·60
Volume of air drawn in by stroke of piston .	Cub. mètre	044·530	066·250	054·000
,, compressed at the ordinary temperature	,,	035·230	054·400	035·300
Gross work produced by the steam . . .	Horses	46·50	34·50	47·60
Effective work transmitted by the engines . .	,,	36·75	27·50	43·00
,, stored in receiver	,,	17·10	14·15	16·17
Work transmitted to the levels, admitting that the borers only return 60 per cent. of the effective work	,,	10·25	8·50	10·00
Proportion of available work of air to gross work of steam .		0·36	0·41	0·35
Proportion of available work of air to actual work of steam .		0·44	0·51	0·38
Proportion of actual work of air in machines to gross work of steam		0·22	0·245	0·209
Proportion of actual work of air in machines to effective work of the engine		0·26	0·32	0·23

If air could be compressed without producing an increase of temperature, its volume at any part of the piston stroke would be in inverse proportion to that of the original volume.

For example, one cubic yard of air at a tension of one atmosphere would be reduced to one-half of a cubic yard at a tension of two atmospheres.

As, however, the heat contained in the one cubic yard of air would remain in the half cubic yard, it follows that the temperature of the latter volume would be materially increased, and that such increase of temperature taking place within a cylinder would cause a certain measure of resistance to the piston; or, in other words, a "loss of work." To reduce this thermic resistance to the compressor piston, various expedients are resorted to. In one apparatus the air is compressed in contact with water; in another the cylinder is surrounded with water; while in a third, in addition to the water-

jacket, a finely-divided spray of water is forced into the cylinder during the time of compressing the air. The diagram, Fig. 99, shows the length of piston stroke A B divided into ten parts, the atmospheric line C D, the curve of compression C *c* according to Boyle and Mariotte's law (viz. that the volume of air is in inverse proportion to the original volume at any part of the piston stroke), the curve *c d* showing the increase of temperature occurring during compression without the presence of a cooling medium, and

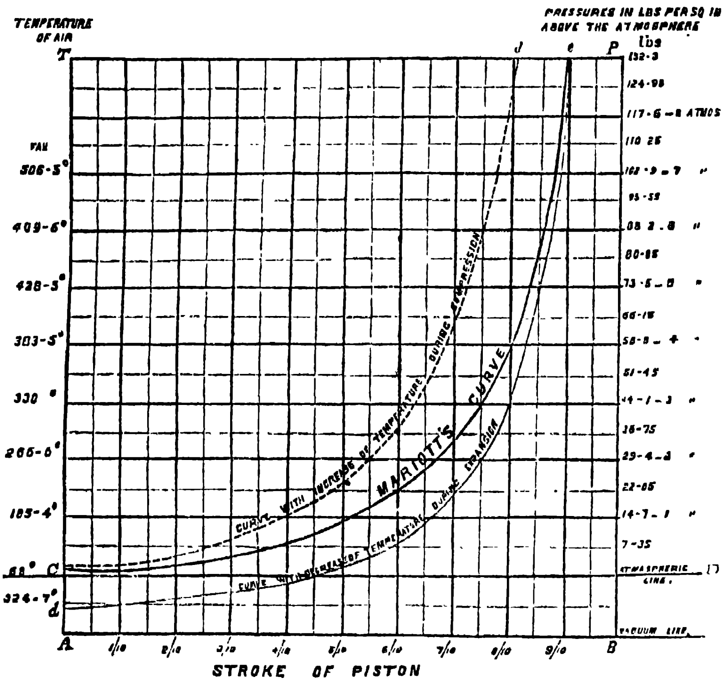

Fig. 99.

the curve *d e* exhibiting the decrease of temperature consequent on release and expansion of the compressed air.

The following table shows the increase of temperature and volume, which result from the compression of a cubic metre of air, from one to eight atmospheres, the air before compression being taken at 68° Fah.; also the loss of work due to such increase of temperature:—

Pressure in Atmos.	Compression with Temperature Constant, Mariotte's Law.		Compression with Increase of Temperature, Due to Heating of the Air.			Excess of Work, due to the Heating of the Air.	Percentage Loss of Work, due to Heating of Air.
	Volume in Cubic Metres.	Work	Temperature Fah.	Volume in Cubic Metres.	Work Foot Pounds.		
	1·000		68°	1·000	....	....	....
	0·500	51·571	186°	0·612	57·348	5·777	9·2
	0·333	82·137	267°	0·459	96·592	14·455	15·0
	0·250	103·142	330°	0·374	128·238	25·096	19·6
	0·200	119·873	383°	0·320	153·341	33·468	21·3
	0·167	133·574	428°	0·281	175·761	42·187	24·0
	0·143	144·877	470°	0·252	195·557	50·680	26·0
	0·125	154·881	506°	0·229	213·415	58·534	27·4

On examining the foregoing table it will be seen that, according to the law of Boyle and Mariotte, one cubic metre of atmospheric air, when compressed to a tension of eight atmospheres, is reduced to a volume of 0·125 cubic metre, while if the compression is effected with increase of temperature, and without loss of heat, it will measure for the same tension 0·229 cubic

metre. The loss of work resulting from such increase of temperature is also shown to be 27·4 per cent.

(*b*) *Engines and Compressors.*—Air compressors may be driven by means of water-wheels, turbines, or water-pressure engines. As, however, the pressure of water under a given head may be regarded as constant throughout the stroke of an hydraulic motor, and the compression of air, commencing from zero, increases in intensity until its delivery to the receiver begins, it is necessary that the number of compressing cylinders and driving gear be arranged and speeded so as to obtain from the constant power of the water its greatest effect.

Steam Engines.—In some of the earlier compressing-machines motion was transmitted from the engines to the compressing cylinders by means of spur-wheel gearing. This arrangement admitted of a high velocity in the steam piston, and of a comparatively slow velocity in the compressing piston; but it rendered the strain unequal on the teeth of the wheels, and sometimes led to their breakage. The more recent practice is to set the cranks of the air and steam cylinders in such a relation to each other that the maximum effect of the steam may be exerted at the time that the air is being delivered to the receiver, or to employ double steam and compressor cylinders, so that the power of one steam cylinder may overcome the resistance offered by the compression of the air in the opposite cylinder. In addition, it is sometimes desirable to provide the engine with a variable expansion valve, and to economise power, by using steam on the piston of considerable pressure, five or six atmospheres, and cutting it off within the cylinder at from three to five eighths of the stroke.

Compressors.—As soon as the compression of air was rendered necessary for the production of power, inventors applied themselves to the arrangement and construction of compressors which should offer some special advantage. Sommeiller introduced at the Mont Cenis Tunnel a wet compressor; Colladon, on behalf of the contractors of the St. Gothard Tunnel, arranged a fast-speed "spray" compressor. In England the wet compressor is but little employed. Fast-speed dry compressors have been mainly adopted, perhaps on account of their comparative cheapness of cost. In Germany, France, and Belgium the mining engineer seems to prefer the wet compressor. Doubtless the latter apparatus is well adapted for mine work. It bears a somewhat similar relation to the fast-speed compressor, that the Cornish engine bears to the locomotive—viz. for its strength, durability, and comparative slowness of speed. In another important item it also exhibits a strong resemblance; it is an economical apparatus, since it may be contrived to give the largest percentage of useful effect for the unit of power expended to secure it. The essential difference between the wet and dry compressor is, that the *wet* compresses the air by means of a column of water moved by a piston, the *dry* by the piston itself, acting directly on the air without the admission of water to the cylinder.

The speed of a wet compressor is limited to about 200 feet per minute. A dry compressor is frequently driven 400 feet per minute, consequently the piston area of the former would seem to require twice the area of the latter to give an equal amount of work. As the cylinder of a wet compressor

will charge itself with 96 parts of the cubic contents of the stroke, while a dry compressor only takes in from 70 to 80 parts, the economic result of the wet compressor is greater.

Fig. 100 shows a vertical section of a wet compressor through the centre of the cylinders. The piston moves horizontally in a cast-iron cylinder C, which is kept full of water. At the extremities of the cylinder are two vertical columns, P′ P, closed at their upper ends. The air is admitted through a rectangular opening, S, in the side of each column. The intake valves, S, are of leather, stiffened with wrought-iron plates, as in mine pump buckets. The discharge of the air into a receiver takes place through gun-metal valves, S′. The movement of the piston within the cylinder causes the water in the vertical columns, P′ P, to rise on one side and fall on the other. Above the falling column of water the tendency towards a partial vacuum causes the admission valve, S, to open and the unoccupied space to be filled with air. When the piston returns in the opposite direction the admission valve closes, the water is driven upwards, and the air compressed until its tension becomes the same as that in the receiver.

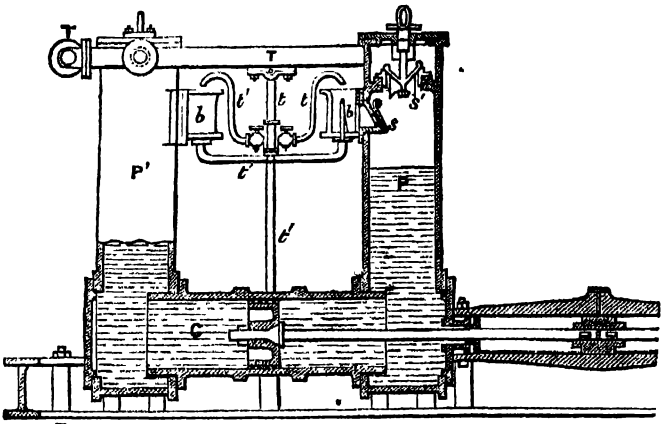

Fig. 100.

The outlet valve, S′, then opens, and as the water rises through and above the outlet valve, it follows that the whole of the air compressed is forced into the receiving vessel by means of the pipe T. A small but adjusted quantity of water is continually supplied to the compressor cylinders by means of the pipe *t* and branches *t′ t*. The water is delivered first into the receptacles *b b*, and then into the cylinders through the inlet valves. To prevent any overflow of water from the receptacles it is drawn off by the breeches and waste pipe, *t′t′*, placed at the bottom.

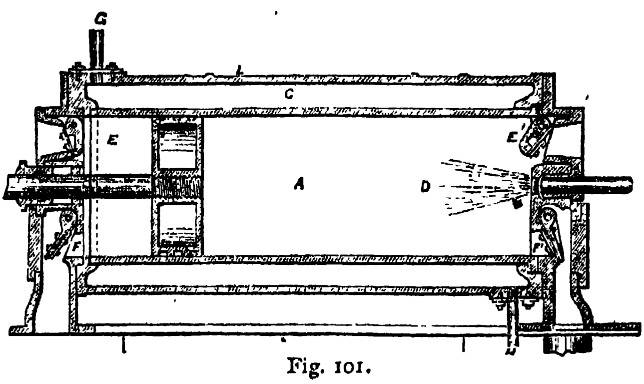

Fig. 101.

In this form of compressor, Darlington has introduced a spray of water immediately under the outlet valves, S′, so as to absorb a larger amount of heat than would otherwise be effected by the simple contact of the air with the vertical water-compressing column.

Fig. 101 is a sectional elevation of a compressor fitted with a water-jacket

and two spray nozzles. A, compressing cylinder; C, water-jacket cylinder encasing the compressing cylinder; D, spray jet; E and E′, inlet valves; F F′, outlet valves; G, pipe for admitting water to the jacket-cylinder; H, eduction pipe.

The following are the principal dimensions of one of the compressors in use at the Blanzy Collieries:—

	Steam Cylinder.	Compressor Cylinder.
Diameter of piston	25¼″	21¾″
Length of stroke	63″	63
Area of admission valve in square inches . .		59
Area of delivery valve in square inches . .	..	48
Speed of piston per second .	4½ ft.	4½ ft.

The volume of air compressed to 45 lbs. per square inch at 25 revolutions per minute is theoretically 450 cubic feet; taking the practical result at 80 per cent. it amounts to 360 cubic feet.

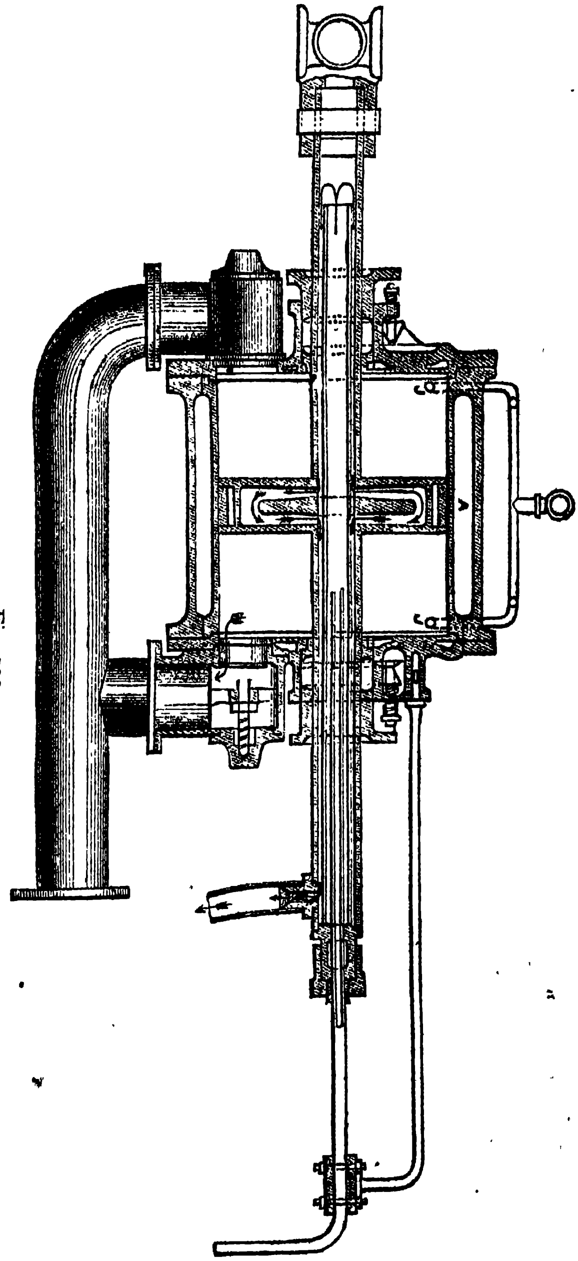

Fig. 102.

Colladon Compressor. — This compressor (Fig. 102) consists essentially of a horizontal cylinder and a hollow piston, the rods of which, also hollow, pass through both ends of the cylinder covers. In each of these covers are two admission and one delivery valve. The distinguishing features of this compressor are the means adopted for the purpose of absorbing the heat developed during the compression of the air, and for keeping the various parts of the apparatus in a comparatively cold condition. The cylinder is surrounded by a water-jacket, A. The piston and piston-rods are provided with internal chambers for the reception and passage of water. Spray nozzles, J J, are also introduced into the cylinder. It is alleged that the volume of water admitted to the cylinder and into the various parts of the apparatus is so adjusted as to limit the temperature to 80° Fah. when the pistons are running at 200 feet per minute, and compressing the air to

a tension of 90 lbs. per square inch. At the Airolo end of the St. Gothard Tunnel twelve of these compressor cylinders were grouped in four sets of three cylinders each. The three cylinders, set side by side, were driven by means of a three-throw crank in connection with wheel-gearing and a turbine. The dimensions of one of these compressor cylinders were, diameter of piston, 18 inches; stroke, 17¾ inches; inlet valves, two in each cylinder cover—total area, 39 inches; outlet valves, one in each cylinder cover—total area, 10¼ inches; theoretical volume of air at 65 revolutions per minute, 1,027 cubic feet, or compressed to 90 lbs. per square inch at 70 per cent. of the theoretical volume, 119 cubic feet.

Carefully conducted experiments with a wet compressor erected at the Saarbruck mines to supply rock-boring machines have been made with the following results :—

No. of Experiment.	Useful Effect of the Compressor at		
	here.	Two Atmospheres.	Three Atmospheres.
	0·94	0·88	0·85
	0·95	0·885	0·855
	0·93	0·88	0 85
	0·95	0·90	0·865
	0 94	0·87	0·83
	0·93	0·85	0·80
Mean	0·94	0·877	0·84

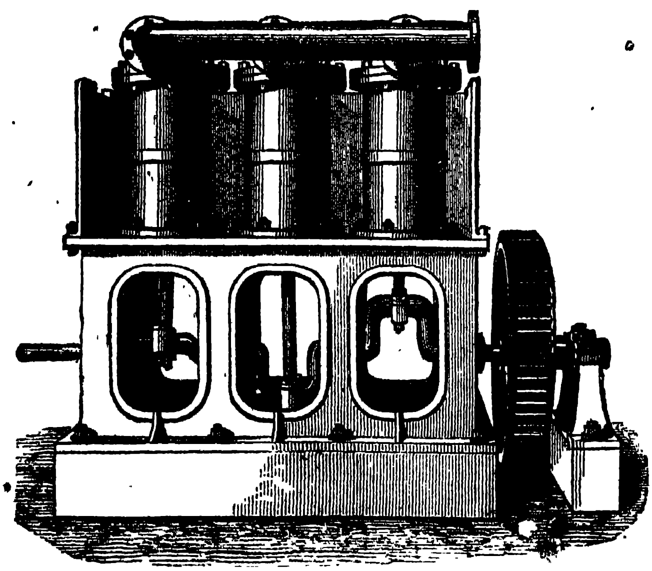

Fig. 103.

Three-Cylinder Compressor.—At the Rushen mines, Isle of Man, a three-cylinder air compressor was erected for the purpose of accelerating the sinking of an engine-shaft, and driving a main level in the lode by means of three *Darlington Boring Machines.* Each cylinder is single acting, the piston-rods being connected with a three-throw crank (see Fig. 103). The cylinders are fixed in a water-tank, while jets of water play into each cylinder during the compression of the air. The inlet and outlet valves are set in the cylinder covers, the outlet pipe to air receiver being in connection with each outlet-valve chamber.

Diameter of each piston	13 inches.
Stroke of piston	18 ,,
One suction valve in each cover, internal diameter 5 inches	19·6 inches area.
Two discharge valves in each cover, diameter 3 inches, equal 7 inches area × 2	14 inches area.
Theoretical volume of air per stroke	1·38 cubic feet.
Or, for the group of three cylinders	4·14 ,,
At a speed of 50 revolutions per minute three cylinders will afford 4·14 × 50	207 ,,
Volume of air compressed to 50 lbs. per inch at 70 per cent. of the contents of the stroke	36$\frac{2}{10}$,,

The following particu-

lars relate to a vertical single-acting compressor, fitted with a water-jacket and spray nozzles designed by Cornet: Engine, two vertical cylinders, steam-jacketed, with Meyer's expansion gear. Cylinders, 16·9 inches diameter; stroke, 39·4 inches. Compressor, two cylinders, diameter of piston 23·0 inches; stroke, 39·4 inches; revolutions per minute, 30 to 40; piston speed, 39 to 52 inches per second; capacity of cylinder per revolution, 20 cubic feet; diameter of valves, viz. four inlet and four outlet, 5½ inches; weight of each inlet valve, 8 lbs.; outlet, 10 lbs.; pressure of air, 4 to 5 atmospheres. The diagrams taken of the engine and compressor show that the work expended in compressing one cubic metre of air to 4·21 effective atmospheres was 38,128 lbs. According to Boyle and Mariotte's law it would be 37,534 lbs., the difference being 594 lbs., or a loss of 1·6 per cent. Or if compressed without abstraction of heat, the work expended would in that case have been 48,158. The volume of air compressed per revolution was 0·5654 cubic metre. For obtaining this measure of compressed air, the work expended was 21,557 lbs. The work done in the steam cylinders, from indicator diagrams, is shown to have been 25,205 lbs., the useful effect being 85½ per cent. of the power expended. The temperature of air on entering the cylinder was 50° Fah., on leaving 62° Fah., or an increase of 12° Fah. Without the water-jacket and water injection for cooling the temperature it would have been 302° Fah. The water injected into the cylinders per revolution was 0·81 gallon.

Dry Compressors.—The arrangement of the dry compressor is nearly similar to that of the spray compressor. No water is introducod into the cylinder for the purpose of absorbing heat developed during the compression of air, but a water-jacket around the cylinder is usually relied upon for that purpose. The result is so unsatisfactory that economy of power may be said to be sacrificed to simplicity of arrangement.

The objections which may be urged against high-speed compressors are —(1) The rapidity with which heat is accumulated within the cylinder, overheating the various parts unless the heat is largely absorbed by means of water; (2) Loss of air with metallic spring pistons, amounting to from 7 to 10 per cent. of the stroke, and increasing largely with low piston velocities; (3) The voidance of air from the cylinder during the closing of the inlet valves, in some cases a serious percentage of the contents of the stroke; (4) The loss of useful effect of the steam consequent on any passage of air from front to back of compressor pistons; (5) The rapid wear and tear of parts incident to a high piston speed; (6) The liability of the valves to "break up" the force or impact of the shutting blow, increasing with the pressure multiplied by the square of the velocity. Against low-speed compressors it may be alleged that the apparatus is large in proportion to the power it will afford, and that the first cost, if distributed on the horse-power of the compressor, is somewhat high.

(*c*) *Receiver and Air Pipes.*—The receiver and air-pipes should be of sufficient capacity to run the boring-machines without exhibiting much variation of pressure. The dimensions of the receiver, as well as the pipes, ought therefore to be in relative proportion to the number of machines to be worked, the cubic quantity of air necessary for running the machines during

a given period, and to the charging power of the compressor. No exact rule can be laid down for determining the dimensions of the receiver; but if its capacity be eight or ten times greater than the volume of air required per minute for the use of the machines, it will probably be sufficient.

Large receivers and air-pipes are desirable (Fig. 104). The boring-machines when well supplied with air will not only deliver their blows more uniformly and with the desired effect, but the friction in passing air through large pipes, from the receiver to the machine, will be inconsiderable. The receiver may be placed vertically, or lie horizontally on the ground, near to, or somewhat distant from, the compressor. To render the receiver complete it should be furnished with relief and stop valves, and, if in connection with a wet compressor, a blow-off cock; and a pipe for returning water to the compressor columns should be added, unless fresh water happens to be available for cooling purposes. In such case the return pipe will not be required, but instead the receiver should be fitted with an automatic arrangement for dis-

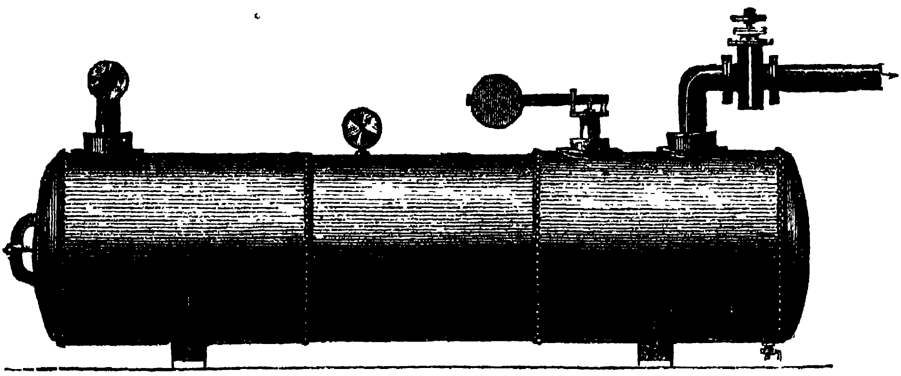

Fig. 104.

charging the water when it may attain a given height within the receiver itself.

TABLE OF RECEIVERS.

Localities.	Designer of Compressor.	No. of Receivers.	Contents.
Mont Cenis	Sommeiller	14	28,000 cubic feet
St. Gothard	Colladon	4	2,225 „
Vieille Montagne	—	1	180 „
Saarbruck	Humboldt	3	740 „
Marihaye	Sommeiller	6	4,250 „
Ronchamp	do.	1	880 „
Anzin	do.	2	1,450 „
Minera	Darlington	1	200 „
Ballacorkish	do.	1	600 „
St. John del Rey	do.	2	400 „
Madonna	do.	1	200 „
Wheal Agar	do.	1	600 „
Moonta	do.	—	— „
Marbella	do.	2	— „

Compressed air must be conveyed in pipes from the receiver to the boring-machines placed at various points underground. During this transmission a loss of work is occasioned by the friction of the air. The results of numerous experiments to determine the value of the loss thus occasioned show—1. That

the resistance is directly as the length of the air main. 2. That it is directly as the square of the velocity of flow. 3. That it is inversely as the diameter of the pipe. The formulæ established from these results and conclusions show that for air-pipes of the diameters usually employed, and for the distances prevalent in mines, the loss of motive force due to the friction of the air in the main is insignificant when the velocity does not exceed 4 feet a second.

The pipes to form the permanent main from the receiver to the boring-machines may be of cast or wrought iron, but in either case they should be provided with faced and scored flanges. Cast-iron pipes are obtainable in 6 or 9 feet lengths; wrought-iron pipes in 12, 14, or 16 feet lengths. If wrought-iron pipes are to be used, cast-iron flanges may be screwed or soldered on the ends. Before cast-iron pipes are placed in position the interior surfaces should be well flushed with water and swabbed, in order to remove any loose sand or scale adhering to the sides. To complete the operation, the interior surface should be covered with a non-corrosive paint. The inside of many a boring-machine cylinder has been partially destroyed through neglect of these simple precautions. The pipe-joints are readily and effectively made by means of a flat ring of vulcanised rubber. The expansion taking place in an air main is best taken up by means of a running joint, or by introducing a short bend of copper pipe. In the levels the main may be laid on the sole, or hung on the side towards the roof, the latter being a position frequently preferred. In some cases it will be useful to place one or more cocks on the main; one fixed at the commencement of the "advance" or terminal pipe is almost necessary. The advance pipe is in some instances formed of one pipe sliding within another, the inner one being drawn out as the forebreast of the level is advanced. To the end of this inner pipe is attached the flexible hose for connecting the permanent main with the boring-machines.

When tunnels have to be driven a long distance, and time is of the greatest value, a reserve main is sometimes fixed to supply air to the borers, during the period when additional pipes are being added to the principal or working main. In metalliferous mines, rock-boring machines will scarcely be required to operate at a greater distance than a mile from the seat of power, and as the number of the machines will be more or less limited for some time to come, pipes of less diameter will suffice than if the air is to be conveyed a distance of 3 or 4 miles, as in the case of some tunnels already executed. For the general main, pipes 3 inches to 4 inches diameter will be large enough; for the secondary or branch part of the main, the diameter need not exceed 2½ inches or 3 inches, whilst for branches from this part of the main, to connect a series of three or four borers, the diameter may be reduced to 2 inches.

(*d*) *Railways.*—In tunnels or mine headings, driven in Europe, a single railway is generally laid for the borer carriage, and waggons necessary for the removal of the débris. In one or two instances the borer carriage has been placed on a wide railway, and the stuff removed by means of waggons running on a narrower gauge line. The advance headings in Europe scarcely ever exceed a width of 9 feet. In America, however, the whole width of the railway tunnel is sometimes carried in the advance heading, which renders a

double and spare line of rails necessary. In driving mine levels, the gauge of the carriage rails may have to conform to the gauge of the waggon required for the removal of the stuff. If no special considerations were necessary other than to determine the best gauge for the borer carriage, the gauge might be fixed at 2½ to 3 feet, and the weight of rails from 18 lbs. to 20 lbs. per yard. In long headings, and where boring carriages are employed, it may be desirable to cut stalls, at from 50 to 100 fms. apart, for the lodgment of the carriage and boring-machines, during the time of blasting the shot-holes and effecting the removal of the stuff. Such stalls will also be found very useful for sheltering the men during the firing operation, for holding the boring tools, machine oil, or; when electric blasting is employed, the apparatus required for igniting the fuses.

Places.	Gauge of Single Railway laid in Middle of Level.		Width of Advance Heading.		Height of Advance Heading.		Area of Heading in Square Feet.	
	Ft.	in.	Ft.	in.	Ft.	in.	Ft.	in.
Mont Cenis . . .	3	3½	9	10	8	6	81	7
St. Gothard, Göschenen	3	3½	8	10	8	2	72	2
,, Airolo .	3	3½	8	6	8	2	69	5
Vieille Montagne . .	4	0	7	4	7	4	53	9
St. Leonard's . .	1	11½	6	7	6	7	43	4
Marihaye . . .	1	7½	7	3	7	3	52	6
Ronchamp . . .	2	1½	7	3	7	3	52	6
Anzin	1	11½	7	10	7	3	56	9
Friedrichsegen . .	2	0	7	0	7	0	49	0
Blanzy	3	3	7	0	7	0	49	0
Gothardbahn . .	3	3½	7	0	7	0	49	0
Marbella . . .	2	0½	7	0	5	0	35	0
Cwmbran . . .	3	0	10	0	7	0	70	0
Maesteg . . .	—		10	0	9	0	90	0
Mustconetcong . .	4	0	27	0	8	0	216	0
Hoosac Tunnel . .	—		24	0	9	0	216	0
Portskewet . . .	1	8	8	0	8	0	64	0
Minera	2	0	6	6	7	3	47	0
Drybrook . . .	2	0	6	0	7	0	42	0
Ballacorkish . . .	2	0	6	6	7	0	45	6
Foxdale . . .	—		5	6	7	6	41	3
Laxey	—		4	6	7	0	31	6
Dolcoath . . .	—		8	0	6	0	48	0
Cam Brea . . .	2	9	8	6	8	6	72	3

(*e*) *Stands and Frames for Boring Machines.*—The economic result obtainable from the application of rock-boring machines is greatly dependent on the form and strength of the stand or frame which may be employed to carry the machines. If a drill is to deliver its blows to the bottom of a hole, in a thoroughly effective manner, it must not vibrate and be deflected, as it were, to any appreciable extent from its axial line, nor should the tool react without giving the full effect of its impact to the stone. A frame, to be satisfactory, must be sufficiently rigid to withstand the reactive twisting effect consequent on the rapid reciprocation of the machines; it must also be constructed so as to admit of being fixed and removed quickly; and afford the widest range possible for directing the drills to various parts of the forebreast, or for angling the shot-holes to such an extent as to ensure, by means of the explosive, the removal of the rock.

Moreover, the stand or frame should be contrived so as to allow ample space for the workmen to move around and to get access to the machines, when the latter are at work.

The several distinctive frames which have been constructed are, the Mont Cenis, which carried ten drills, and weighed eighteen tons; the Dubois-François, mounted with six drills, weighing from three to four tons; the Beaumont "Camel," of considerable weight, carrying four machines; and the Darlington stand, three hundredweight, for carrying two machines.

Mont Cenis Stand.—This stand, consisting of a framework of wrought iron, was 24 feet long, about 6 feet wide, and 6 feet in height. It ran on four wheels, and carried the boring-machines, air-pipes, and a vice for effecting any small repairs required to the boring tackle during the boring operation. When in working position the wheels of the stand were lifted from the rails, so as to obtain the entire weight of the apparatus for the purpose of resisting the percussive action of the machines.

Dubois and François Stand.—These stands, used in mine levels, are arranged to carry two or four machines. The length of a stand mounting four machines is 10 feet, height from rails $3\frac{3}{4}$ feet, width outside of rails 3 feet. The frame of the stand is of wrought iron, and includes four screw-cut columns; viz. two to which the machines are attached, and two, distant about $5\frac{1}{2}$ feet, which are provided with loops for supporting the front ends of the machines. The stand is mounted on six wheels, each about 9 inches diameter. These wheels are so placed in relation to the weight of the frame and the position of the machines as to allow the latter to drop, so as to angle close to the bottom of the level. Each machine is connected by means of a short hose pipe to a small air reservoir, fixed near to the top of the frame. When the machines are at work the stand is lifted by means of screws which bear on the surface of the rails; the dead weight of the stand is consequently obtained and utilised in resisting the impact of the machines when these are at work.

Beaumont's Camel.—The Beaumont camel is composed of a trolley, fitted with a vertical column, four arms, two extending each side of this column, and a small air and water reservoir set at the rear end of the trolley platform. The trolley is mounted on four wheels, each 10 inches in diameter and $4\frac{1}{2}$ feet apart. These wheels run on a $2\frac{3}{4}$-feet gauge railway. The width of the trolley platform is $2\frac{1}{2}$ feet; the diameter of the vertical column, 15 inches; height from face of rails, 6 feet; diameter of horizontal arms carrying the boring-machines, 8 inches. The central boss holding the two arms is fitted with an hydraulic pump. In each arm is an hydraulic ram. To fix the arms for boring purposes the outer ends of the rams are pressed against the sides of the levels. In this stand its dead weight is not required for the purpose of keeping the boring-machines in line of the shot-hole. A diagrammatic illustration of this stand is shown in Fig. 105.

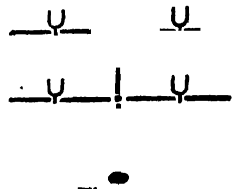
Fig. 105.

Darlington's Stand.—This stand, employed for driving mine headings, is composed of a vertical and two horizontal bars. The vertical column is clamped to the roof during the boring operation; the side bars are set so as to require but once shifting to bore the whole number of holes. In order to use this stand with ease and facility it is taken to and from the forebreast on a small trolley arranged for that purpose.

This trolley is also fitted with a platform for holding the boring-machines as well as an air cylinder, having one inlet for the air main, and two outlets, one connecting each machine by means of a short piece of rubber hose. The arrangement of the stand is such as to admit of boring

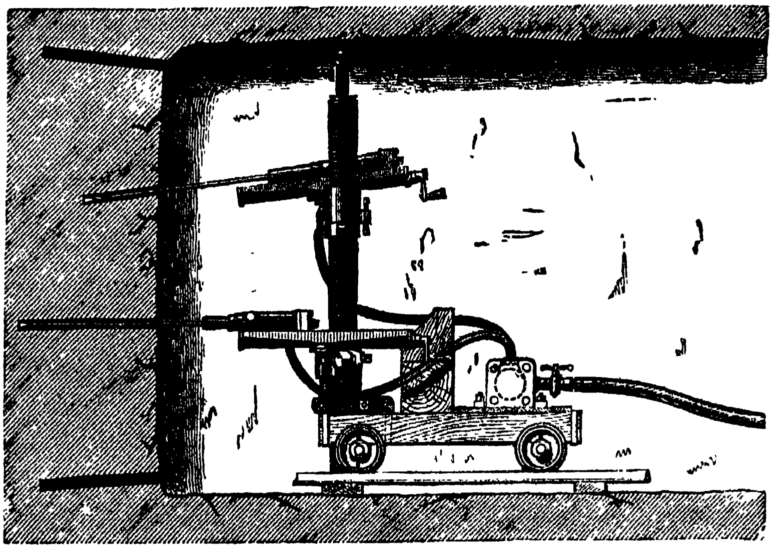

Fig. 106.

the holes, and blasting the ground, in vertical or horizontal "cuts," as may be desired.

Fig. 106 represents a vertical side elevation of the trolley, clamping column, machine arms, and boring-machines. The column is shown attached to the trolley; but before the machines are set to work it is disconnected, and the trolley shifted a few feet to the rear. This separation of the trolley from the column allows the workman to pass freely from one side of the column to the other. When the stand is withdrawn, it is detached from the top and sides of the level, clamped to the trolley, and dropped, so as to lie at an angle of about 45° to its vertical position.

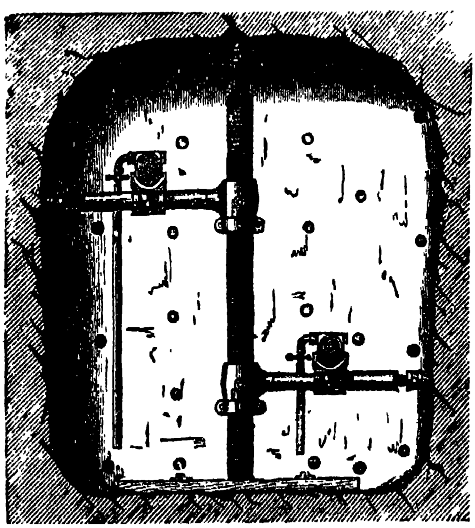

Fig. 107.

Fig. 107 represents a front elevation of the stand without the trolley, the boring-machines in working position, and the position of holes supposed to be bored. To drill these holes the upper and lower arm is unclamped *once* during the boring shift, turned and clamped to the opposite side. These operations, together with the angling and traversing range of the machine, suffice to secure the requisite positions for drilling the whole of the holes.

Fig. 108 shows the stand and trolley at the end of a level. In this view the boring-machines, horizontal arms, air cylinder, and rails, are illustrated. The method of boring the holes from a fixed point on the bar, simply by angling the machines, is also rendered apparent. To use two machines three men are necessary; viz. one man to each machine, and one man between the machines at the forebreast to change the tools, oil the piston-

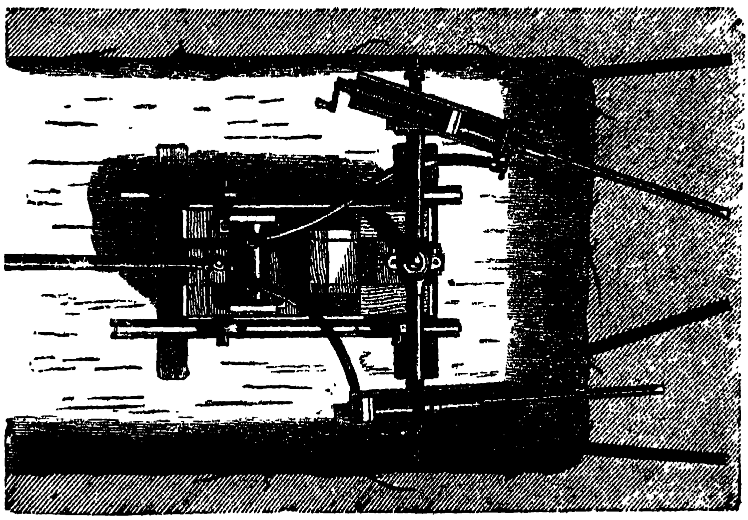

Fig. 108.

rods, direct the bits on commencing the holes, and to supply the holes with water.

The general form of the stand used at the Severn Tunnel, Portskewet, and which carried two Geach boring-machines, is shown in Fig. 109. The platform trolley was provided with a vertical bar 5½ feet long, to which was

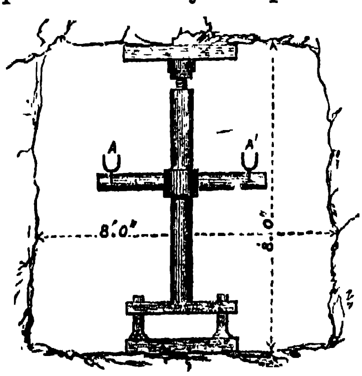

Fig. 109.

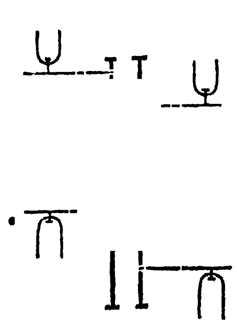

Fig. 110.

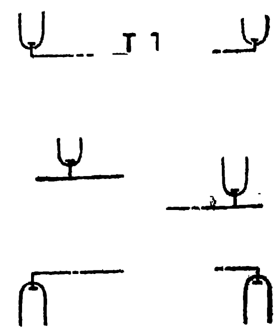

Fig. 111.

attached a horizontal arm. To fix this bar it was screwed to the top and bottom of the heading. The machines were clamped at A A', about four feet from the sole of the level. The holes were bored by radiating the machines from these points.

Figs. 110 and 111 are diagrammatic illustrations of stands employed in France for carrying four and six boring-machines. In the first of these two machines are supposed to be *over* and two *under* the bar, while the second shows

the position of four machines *over* and two *under* the bar. These bars, together with the machines, are so placed as to admit of the perforation of the forebreast without altering their normal positions. In Fig. 109 one machine commands one quarter of the area of the forebreast; in Fig. 110 one machine deals with one-sixth part of the area of the face.

Shaft-sinking Stand.—The stand, introduced at the Minera mines, North Wales, in 1876, is shown in Fig. 112. It consists of a vertical bar 18 feet long, and two arms, the length of which is dependent upon the diameter of the shaft. For the Darlington boring-machines the arms are set 3½ feet from the bottom of the shaft, the arms are clamped to the sides of the shaft, and the boring-machines worked and shifted on the arms, so as to bore the holes shown in the illustration. When the whole number of holes are drilled the horizontal bars are unclamped, the vertical column loosened from the stay piece of timber, which at first is 6 feet from the bottom of the shaft, and the apparatus lifted 20 or 30 feet.

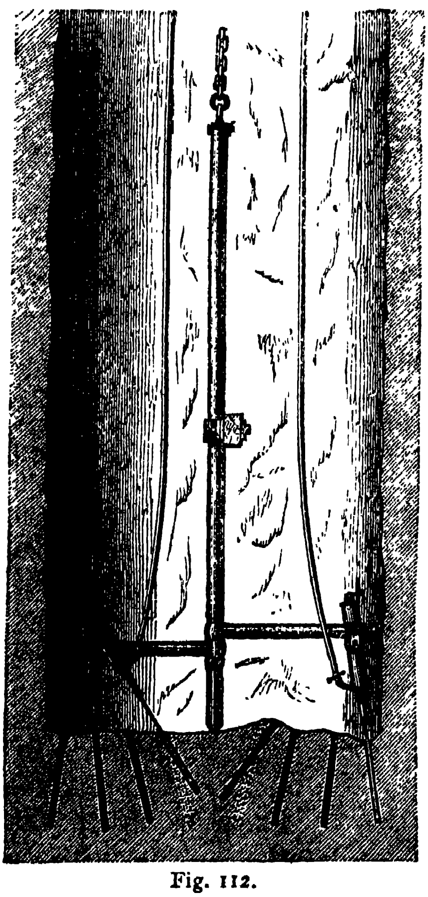

Fig. 112.

When the shaft bottom is cleared, say to a depth of 3 feet, for a second boring shift, the bar is dropped to the bottom, and clamped to the stay piece, this time 9 feet from the bottom. Four sinks, each 3 feet deep, can thus be made before it will be necessary to place a second clamping or cross-piece within 6 feet of the bottom. At the Ballacorkish mine, in the Isle of Man, a pump 8 inches diameter was made the central sinking column. This pump was provided with a windbore of cannon-like strength, around which two horizontal arms rotated. Each arm carried a boring-machine. About 12 feet from the bottom of the shaft a wrought-iron pent-house, provided with doors, encircled the pump, and protected the men who worked underneath.

The "lift," at first 12 fathoms long, hung to screws 14 feet long, was so arranged as to discharge the sump water through a nozzle piece, one of which was placed in the column, at distances 18 feet apart. The pump-rod was arranged to slide on a "set-off" attached to the main rod, so that both pumps and rods were "dropped" together.

The whole was arranged and placed in the shaft previous to the commencement of the sinking operation.

(*f*) *Rock-boring Machines.*—The first inventor of a rock-boring machine seems to have been Trevithick. In the year 1813, when his attention was directed to the subject, Cornwall was not only the chief seat of our mining

industry, but, through the startling improvements effected in the steam-engine by Watt, Murdoch, Trevithick, Woolf, and others, an impetus was given to mechanical inventions which extended far beyond the confines of the county, and men were stimulated at home and abroad to substitute as far as possible mechanical appliances for manual labour. Some forty years, however, passed away before the idea of boring shot-holes, by means of machinery, was rendered practicable. The exigencies of the Mont Cenis Tunnel induced Bartlett to devise a steam rock-boring machine. Later Sommeiller invented the machine which bears his name, and showed how it could be worked by compressed air. Following Sommeiller's success, in the Mont Cenis Tunnel, Italian, German, French, Swedish, American, Australian, and English engineers addressed themselves to the subject of inventing, contriving, and improving rock-boring appliances. Machines 10 feet long, beset with complicated gear, are now replaced by machines 3 feet long, presenting little more than the cylinder, valve, and forwarding screw. All real and permanent improvements have tended in the direction of increased strength and simplicity of parts. In more particularly tracing the development of inventors' ideas for expediting tunnelling and mining operations, it will appear that they group themselves into:—1, forming the shot-hole by a revolving drill, and blasting the hole itself; 2, removing the entire area of the heading without the use of an explosive, either by means of a huge percussive, or a pressure cutting-machine; 3, boring shot-holes by means of a small percussion-engine. The failure of the first method, that of employing an ordinary steel tool in hard silicious rock, was soon rendered apparent; the tool, instead of abrading the stone, was almost immediately destroyed. The second method—substituting mechanical for mechanical and chemical force, also proved objectionable when applied to hard crystalline rocks. Apart from such machines, blocking as it were the forebreast, the mechanical power required for performing the work was not only excessive, but the progress slow, and the greatest difficulty experienced in keeping the tools in condition for doing their work. The third method—the use of percussion borers in combination with strong explosives, is the one which has been, and is likely to be, attended with permanent success. In perforating a heading with the requisite number of shot-holes, only a minimum expenditure of mechanical power is required; the chief work, that of removing the rock, being effected by powder or dynamite. In a percussion borer the movements required to form a hole are of a threefold character—1, a reciprocatory movement of the piston and tool to disintegrate the rock; 2, turning the piston and tool during the reciprocatory movement; 3, advancing the tool as the hole is deepened.

In some rock-boring machines these movements are automatically performed, and such automatic movements are desirable when four or six machines are worked together; but the forwarding or advance movement will be liable to fail in its object unless the rock be of uniform structure and hardness. In other boring-machines the automatic movements are confined to the reciprocation and rotation of the piston, while in some, the piston and tool are rotated by hand. When only a single boring machine is in use, a merely reciprocatory movement may suffice, but the

rejection of a simple automatic arrangement for rotating the piston and tool is by no means desirable. In many cases the object of an inventor has been to make his machine light, and of small dimensions. As the miner has greatly encouraged the idea of employing a light machine, it may be observed that this condition, in itself, has rendered light machines all but useless for practical work, and enabled the miner to cite instances of failure, where success could hardly have been expected.

To perforate a face of rock quickly several conditions must be observed:—1. The machines must perform their work with certainty. 2. The number of machines should bear some general relation to the area of the face. 3. Stands are requisite for carrying the machines, not only as a means to keep the "bit" in the line of the hole, but to admit of angling and shifting the machines quickly.

Further, the use of stands will permit the workmen to exercise much freedom in their movements, and enable machines to be employed which will bore deep holes without changing the tool. Boring-machines of the ordinary form drill the shot-holes in the same way as the common hand borer. The borer is attached directly to the piston-rod and reciprocates with it. The piston and rod constitute as it were a part of the boring tool, and the movement as well as the blow is obtained either by admitting or exhausting the pressure fluid to the front and back of the piston, or by the maintenance of a constant pressure on one side of the piston only and admitting or exhausting the pressure fluid from the other side. Most inventors adhere to the ordinary method of moving a main piston and use a valve for that purpose, but Darlington dispenses with a valve and distributes the pressure fluid by means of the piston and portways in the cylinder. He also obtains the reciprocating movement and blow either by keeping a constant pressure of air on the upper or under side of the piston, and admitting and exhausting the air from one side only. This arrangement enables him to make a very simple, durable and effective machine. In order to rotate the piston and tool to a certain extent during the back stroke of the piston, the rifle bar, nut, and ratchet-wheel designed by Jordan and Darlington at the end of the year 1865, and patented by them in 1866, is employed in most of the machines in use. The advance of the boring cylinder and tool, as the hole is deepened, is generally effected by an ordinary screw running in a nut attached to the cylinder.

The Darlington Rock Drill consists essentially of only two parts, the cylinder with its cover and the piston with its rod. The cover when bolted on forms a part of the cylinder; the piston-rod is cast solid with the piston, and is made sufficiently large at its outer end to receive the tool. These two parts constitute an engine; and with less than one fixed and one moving part, it is obviously impossible to develop power in a machine by the action of an elastic fluid. The piston itself is made to do the work of a valve in the following manner:—The annular space affording the area for pressure on the fore part of the piston gives a much smaller extent of surface than that afforded by the diameter of the cylinder (see Fig. 113), and it is evident that by increasing or diminishing the diameter of the piston-rod, the area for pressure on the one side of the piston may be made to bear any desired pro-

portion to that of the other side. The inlet aperture, or port X, being in constant communication with the interior of the cylinder, the pressure of the fluid is always acting on the front of the piston; consequently, when there is no pressure upon the other side, the piston will be forced backwards in the cylinder. During this backward motion the piston first covers the exhaust port D, and then uncovers the equilibrium port Y, by means of which communication is established between the front and back ends of the cylinder, and consequently the fluid is made to act upon the upper side of the piston. The area of the back face of the piston being greater than that of the front face, by the area of the piston-rod, the pressure upon the former first acts to arrest the backward motion of the piston, which, by its considerable weight and high velocity, has acquired much momentum, and then to produce a forward motion, the propelling force being dependent for its amount upon the difference of area on the two sides of the piston B. As the piston presses down, it cuts off the steam from the back part of the cylinder and opens the exhaust. The length of the piston is such that the exhaust port D is never open to its front side; but in the forward stroke it is open almost immediately after the equilibrium port is closed, and nearly at the time of striking the blow. The quantity of fluid expended in this single-acting machine is only that which passes to the back end of the piston, since that which is used to effect the return stroke is not discharged. In a second form of the drill the pressure fluid is kept constantly on the *top* of the piston and exhausted from the underside. The distribution of the pressure fluid is effected by means of the piston and portways in the cylinder, precisely similar to the drill in which the pressure fluid is kept continually on the underside of the piston. Other forms of single-acting drills have been devised by Darlington, such as exhausting the pressure fluid through the piston and piston-rod, and by means of annular spaces in the piston keeping the induction and exhaust portways and passages in the cylinder. In a double-acting drill, instead of keeping the pressure fluid continually against the smaller surface of the motive-distributing piston, the pressure is alternately admitted to, and exhausted from, both sides of the piston. To effect this the piston is made sufficiently long to admit of a groove being turned

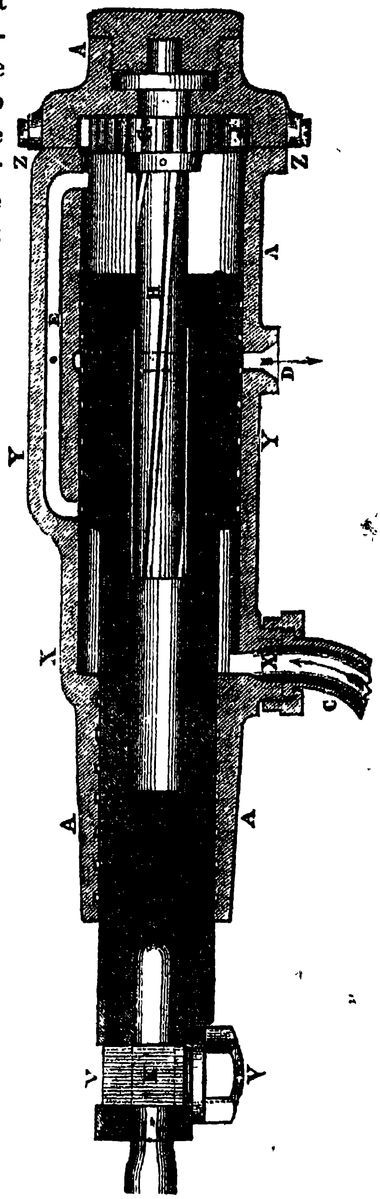

Fig. 113.

in it of such a length as to always be in communication with the pressure portway formed about the centre of the length of the cylinder. Two induction passages and two exhaust portways are also cast in the cylinder. The motive piston, in its passage across the portways, admits the pressure fluid to one induction portway communicating with one end of the cylinder, and at the same time it uncovers one exhaust portway and releases the pressure from the opposite end of the cylinder. The objects gained by the foregoing method of obtaining reciprocatory motion for rock-boring machines are—(1) There is only one working part used in obtaining the motion of the solid piston and rod, which cannot well be destroyed by the effect of rapid and heavy blows given to the boring tool. (2) Great rapidity of motion and efficiency

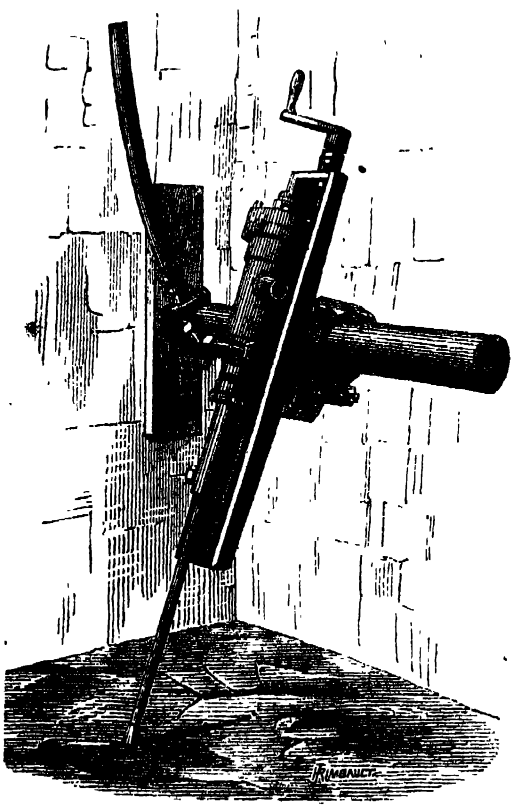

Fig. 114.

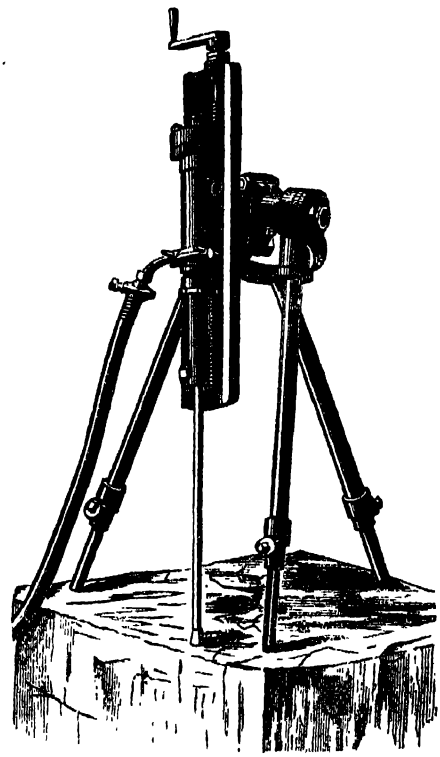

Fig. 115.

of blow are obtainable by means of large portways and passages, which can be advantageously employed. (3) The speed, weight of blow, and length of piston stroke can be varied at the will of the operator. (4) Stoppages due to displacement of valves cannot occur: while with constant pressure maintained on the piston, the piston can never be in equilibrium, but it must start at any part of the stroke. Fig. 114 shows a single-acting cradle-drill mounted on a stretcher-bar for sinking shafts. In this drill the cylinder is forwarded in the cradle, as the shot-hole is deepened by means of the handle and screw attached to the cradle. Fig. 115 illustrates a double-acting drill in which the cylinder works in a nut attached to the clamp. This cylinder is advanced or withdrawn from the shot-hole by means of a

hand-wheel or handle at the top. Fig. 116 shows a single-acting drill mounted for quarry work. In order to keep this drill firmly in position during the boring operation, heavy weights are placed on the legs.

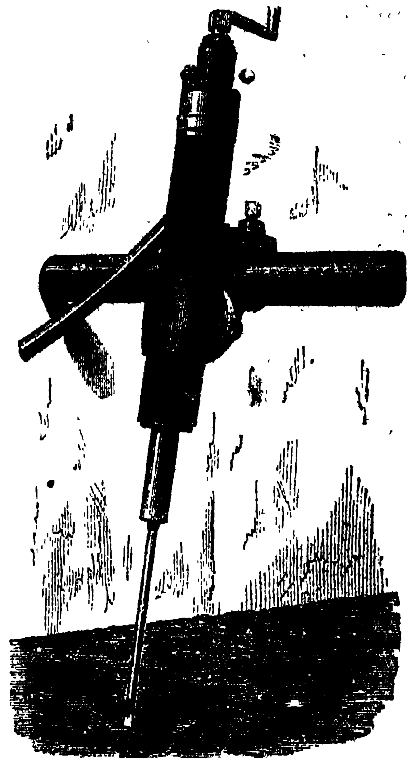

Fig. 116.

Among the results obtained by the use of these machines, those connected with the sinking of an engine-shaft at Ballacorkish mine, Isle of Man, may be noticed. Rock, tough Clay-Slate enclosing strings of quartz: diameter of shaft, 10½ feet; area, 86 square feet; depth of shaft from surface, 50 fathoms; number of shot-holes bored in bottom of shaft, 22 to 24; diameter of holes, 1⅛ inch; depth of shot-holes, 3½ to 5 feet; number of boring-machines employed, 2; pressure of air required, 50 lbs. to 55 lbs. per square inch; number of men employed, 9; lineal depth sunk weekly, 12 feet; time occupied in boring the holes, 21 hours; in charging and blasting the shot-holes, 12½ hours; in hauling the stuff, 73 hours; total, 106½ hours; to which must be added, dropping the pump-work, 10 hours; hindrances, 11 hours: together, 21 hours. The following are the relative results attending the sinking of this shaft by hand, and by hand supplemented by machine labour:-

	Hand Labour.	Hand and Machine Work.
	£ s. d.	£ s. d.
Contract price	31 0 0	13 0 0
Compressing air	—	1 0 0
	31 0 0	14 0 0
Number of men employed	12	9
Lineal depth sunk per week	2¼ feet	12 feet
Wages earned weekly per man	18s.	45s.

(*g*) *Boring Tools or Bits.*—The piston or tool holder of a rock drill is generally rotated by means of a spiral bar running within the piston.

The length of the rotating movement will depend upon many circumstances, notably upon the angle given to the spiral bar, on the length of stroke, and on the velocity of the piston. Some pistons will therefore rotate to a greater extent than others, stroke for stroke. This result, together with the fact that rocks are of varying degrees of hardness, frequently fissured, presenting joints and faces to the point of the tool, have brought into use bits of various forms. The flat, cross, X, and Z shape bits are, however, chiefly employed. The flat bit is perhaps best adapted for drilling hard, compact rock; the cross and X bits for jointy and fissured rock; the Z-shaped bit for drilling holes in soft rocks, such as slate and shale, Fig. 117.

In ordinary mine headings, and in the employment of comparatively small boring-machines, the diameter of the boring steel may vary from

¾ inch to 1¼ inch. All boring tools should be straight, and be as it were a true prolongation of the axial line of the piston. A crooked or eccentric tool will not only lessen the effective working of the machine, but it will often cause such an amount of friction by rubbing on the side of the hole as to bring the piston to a state of rest. In changing a tool care must be taken that the cutting edge of the one to follow is not wider than the cutting edge of the tool withdrawn. In the tool withdrawn it will be often found, owing to the vibration of the machine, that the corners have been partly removed; the cutting edge of this tool is therefore that portion not rounded, or that which is parallel to the face of the hole. Many instances occurred in the rudimentary stages of boring when machines were alleged to be useless; the fact having been that the cutting edge of the second tool was wider than that of the tool withdrawn, which tool, forced into a tapered hole, necessarily wedged itself fast, thereby stopping or retarding the working of the machine. As a common rule, the width of the different sets of boring tools at their cutting edges should vary about ⅛ of an inch from each other; but if the rock should be unusually hard and the corners of the bit readily removed, the difference between the widths of the bits should be greater.

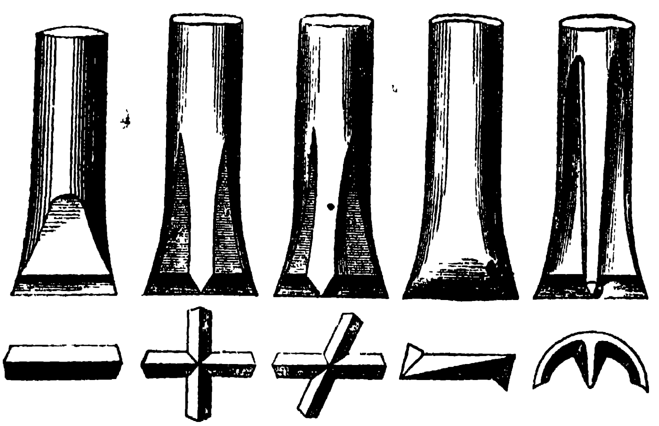

Fig. 117.

Flat Bit. Cross Bit. X Bit. Z Bit. Warsops Bit, for making round holes.

No rule can be strictly laid down for determining the time and power requisite to bore holes of different diameters; but experience seems to show that if a hole 12 inches deep and 1 inch diameter takes four minutes, a hole 2 inches diameter and of like depth, bored with the same machine, and under the same conditions as to pressure of air and number of strokes per minute, will take sixteen minutes. In other words, the machine and pressure of air being the same, the time and power required to bore holes to a given depth are as the squares of their diameter. The degree of temper to be given to the bit when sharpened must be suited to the hardness of the rock to be penetrated. Straw-colour is generally desirable when the tool has to operate on very hard rock, and light blue when the rock is only of moderate hardness.

(*h*) *Water and Ventilating Apparatus.*—In boring shot-holes, particularly deep ones, in clayey or "sticky" rock, it is necessary to remove the disintegrated sand or clay as it may be produced. If this is not done the stuff will "bind" so firmly as to wedge the "bit" fast, and thereby stop the progress of the boring. An apparatus employed for the purpose of washing the stuff from the holes consists of a cylindrical vessel mounted on

a trolley, which usually stands behind the boring-frame. By applying the air pressure to the surface of the water, and extending a pipe from the bottom of the water within the vessel to the forebreast, a stream of water may be projected to any hole. To regulate the flow a small cock should be fixed on the nozzle pipe. A simple method for obtaining the water is to connect a small pipe an inch diameter to the pump work, to give the water a head of 20 or 30 fathoms, and to apply the water to the holes by means of a flexible tube and nozzle piece attached to the end of a small hydraulic main.

The rate of boring a dry and wet hole is found to vary from 1 dry to 1·5 wet. A plentiful supply of water will in most cases not only quicken the rate of boring, but it will economise the use of power to a proportionate extent.

(*i*) *Explosives.*—Explosives for blasting purposes may be divided into two classes, viz.:—

Slow, or rending compounds, as (a^1) ordinary black powder.

Quick, or shattering compounds—

(b^2) Nitro-glycerine.
(c^3) Dynamite.
(d^4) Nitrated gelatine.
(e^5) Lithofracteur.
(f^6) Cotton powder, or tonite.

(a^1) *Blasting powder* is a mixture of saltpetre, sulphur, and charcoal. In a good powder the grains must be firm, hard, dry, free from dust, not ready to absorb moisture from the air, of uniform colour, and a small portion, when ignited on white paper, should not burn it.

An analysis of seven different kinds of blasting powder, according to Rziha, gave the following average results:—

Saltpetre	63·33
Sulphur	15·89
Charcoal	19·39
Hygroscopic moisture	1·36
	99·97

Powder may be ignited by impact, but with great difficulty. It is, however, readily fired by the application of burning tinder or yarn, a steel or platinum wire rendered red hot, by an electric current, or by fulminating powder in contact with an electric spark.

(b^2) *Nitro-glycerine* is a light yellow, clear, oily liquid. Its specific gravity is about 1·6; when transparent it freezes at a temperature varying from 39° to 46° Fah. It is dissolved with difficulty in water, but readily in pyroligneous spirit or alcohol, the solution being non-explosive. Pure nitro-glycerine will not spontaneously decompose at an ordinary temperature, but if it should be associated with free acid, decomposition is apt to occur. At 320° Fah. red vapours are evolved, and at 356° Fah. its exploding-point is reached. The gases evolved on explosion are—

Carbonic acid	45·72
Binoxide of nitrogen	20·36
Nitrogen	33·92
	100·00

The temperature of the gas at the instant of the explosion of nitro-glycerine is placed by Trauzl at 839·9° Fah.

(c^3) *Dynamite* was patented by Nobel in May, 1867. The highest, or No. 1 quality, consists of 75 per cent. of nitro-glycerine and 25 per cent. of an infusorial earth, known as *kieselguhr*. Dynamite is divided by the Rhenish Dynamite Company into three classes—

No. IA,	containing	75 to 77	per cent.	of Nitro-glycerine	and	25 to 23 per cent.	*Kieselguhr*.
" I	"	70 " 71	"	"	"	30 " 29 "	"
" II	"	60 " 61	"	"	"	40 " 39 "	"

No. IA is applicable to the hardest and most resisting rocks, such as quartz, porphyry, and basalt, as also to the removal of ground in small headings.

No. I. may be used for similar classes of rocks when less resistant, and in levels of large sections, also in blasting Limestone, gneiss, and Granite.

No. II. is adapted for all sorts of soft rocks, and is well suited for assisting No. IA quality dynamite, by placing the latter at the bottom and the former upon it in very deep holes, or for the removal of the "side cuts" after the "centre cut" is blown out.

The safety of dynamite is alleged to lie in its soft, mealy consistency, constituting, as it were, a cushion, a physical condition of great importance in lessening the chance of its exploding when somewhat roughly handled.

At a temperature of 46° Fah. dynamite hardens into a mottled whitish substance. When frozen it cannot be readily fired. In a pulverulent condition it can be more easily exploded, although with diminished violence, than when fired in a pasty state. The firing-point of dynamite is 356° Fah. If ignited it *burns* slowly, evolving fumes of a deleterious character. When instant and complete combustion is effected by detonation, the gases evolved are innocuous; but if the dynamite should be only partially detonated, hyponitric fumes will be given off, offensive to the miner, and deleterious to his health. Nobel on this subject has remarked: "The frequent occurrence of bad fumes in mines only proves that dynamite is injudiciously used. The general mistake consists in not securing carefully the detonation cap to the fuse, and especially the fuse to the cartridge. In charging, the miner, under such circumstances, easily draws fuse and cap out of the cartridge, leaving them separated, so that the cap cannot possibly exercise its detonating effect. What then takes place is this: part of the dynamite burns, emitting hyponitric fumes, and part generally explodes under the influence of accumulating heat and pressure. Thus the charge goes off, but with a far inferior effect as compared to that of a proper detonation, and with the emission of a great quantity of red fumes of hyponitric acid." No. 1 dynamite is estimated to be about six times stronger than black powder in its effective or shattering force.

In reference to this explosive, Drinker observes: "It is unquestionably a safer material to transport, handle, use, or store than black powder. To explode it heat and strong percussion are necessary."

While Nobel in effect states: "There are no accidents on record due to its spontaneous combustion in mines. Local accidents are almost exclusively to be attributed to injudicious thawing of nitro-glycerine preparations,

to reckless removal of the tamping in bore-holes after a misfire, and to the careless handling of detonators. That comparative immunity from accidents is due to safety from fire where small quantities are dealt with, and to the absence of danger in loading bore-holes, since it is useless to ram the tamping.

(d^4) *Nitrated Gelatine.*—It is found that a comparatively small quantity, 6 to 8 per cent., of a nitrated cellulose, prepared from cotton in a peculiar manner, has the property of transforming nitro-glycerine into a gelatinous explosive. Gelatine may be formed of—

Nitro-glycerine	86·4
Soluble gun-cotton	9·6
Camphor	4·0
	100·0

The specific gravity of this material is 1·6. Its alleged characteristics are—

1. It may be preserved intact for an indefinite length of time.
2. It fails to give off nitro-glycerine even under extreme pressure.
3. It is unaffected by violent shocks or vibration.
4. It is not affected dangerously by fire, but burns quietly and without explosion.

(e^5) *Lithofracteur* is a nitro-glycerine compound.

According to Ulex, chemist of Hamburg, who analysed a sample, it contained—

Nitro-glycerine	70 parts.
Nitrate of barium	5 „
Coal dust	2 „
Infusorial earth (Kieselguhr)	23 „
	100

Trauzl states that lithofracteur explodes at 248° Fah., and is more sensitive to variations of temperature than ordinary dynamite.

(f^6) *Cotton Powder or Tonite.*—This explosive, known as tonite, is a nitrated gun-cotton, produced in a granulated form, and compressed into cartridges of various dimensions to suit the miner's requirements.

When highly compressed its density is nearly equal to that of dynamite. Slowly heated, its firing-point is said to be 360° Fah.; when suddenly heated, it is 482° Fah. One of the products arising from the combustion of this explosive is carbonic oxide, a highly noxious gas. The relative power of various explosive substances, when compared bulk for bulk, is given by Nobel as follows:—

Nitro-glycerine	100
Dynamite (No. 1)	74
Lithofracteur	53
Gun-cotton	45
Curtis and Harvey's blasting powder, fired by detonators	17·5

Fulminate.—The readiness with which fulminate of mercury may be fired makes this salt an excellent medium for effecting the explosion or detonation of other substances, such as pure gun-cotton, dynamite, and nitro-glycerine compounds. Properly-made fulminate detonators are perfectly safe; and as their cost is but small when compared to the cost of a

bore-hole and the requisite blasting material, none but the best detonators should be employed. Mistaken economy, or carelessness in using unreliable detonators, are errors almost fatal to the attainment of a quick rate of advance, either in a level or a shaft. Some of the characteristics of fulminate of mercury are: it explodes violently when struck or heated to 367° Fah., or when touched either with strong sulphuric or nitric acid, also when in contact with the electric spark.

Detonation.—To the researches of Roux and Sarrau is chiefly due the light thrown on the possibility of producing two kinds of explosion in the same substance—one by the application of heat and percussion, the other by flame-heat.

Heat and percussion are produced in an explosive by the ignition of fulminate of mercury, which in itself possesses a detonating quality.

Detonation may be defined as the instantaneous decomposition of an explosive. When gunpowder is fired in the usual manner, combustion takes place, each grain burning from the surface inwards; but when nitro-glycerine compounds are ignited by means of fulminate of mercury, the mass explodes simultaneously, or nearly so. In one case the rupturing force may be said to be gradually developed, in the other instantaneously produced. The following table, by Roux and Sarrau, gives the relative strength of three well-known explosive compounds when simply fired and detonated:—

	Simple Explosion.	Detonation.	Relative Weight of Gases.
Gunpowder	1·00	4·34	0·414
Gun-cotton	3·00	6·46	0·850
Nitro-glycerine	4·86	10·13	0·800

From the foregoing figures it will appear that an enormous instantaneous force is gained by detonation over the simple explosion of either of the compounds enumerated; while a brief consideration of the general facts already adverted to will suffice to show that if high speeds in levels or shafts are to be obtained by means of boring-machines, the strongest explosives must be employed and detonated, so as to dislodge the rock under all the conditions in which the bore-holes may be placed, and that it will be desirable to shatter the rocks into fragments for effecting their immediate removal.

Detonators.—Detonators are now so well known as to render any description of them unnecessary. Dynamite may be completely detonated by means of a treble detonator, if uniformly plastic. On the other hand, if hard, or if it should present a mottled appearance, a quintuple detonator may fail to effect the object of complete detonation.

(*k*) *Electric Blasting.*—A series of shot-holes charged with dynamite may be simultaneously fired by means of *high* or *low* tension electricity. High-tension electricity is obtained by a frictional or dynamo-electric machine; low-tension electricity by a galvanic battery, or low-tension exploder.

In employing high-tension electricity it is necessary that the leading or positive wire should be *well insulated*, otherwise a serious leakage of the electric charge is apt to occur, especially if the wire should happen to be in contact with the earth, or with any conducting material.

For the conveyance of low-tension electricity the insulation of the leading

or positive wire need not be perfect; but the copper forming this wire should be of comparatively large section.

In the use of high-tension electricity the line resistance upon the current is but small; consequently, with a well-insulated wire, most of the electricity produced may be conveyed to fuses placed at considerable distance from the firing-machine. On the other hand, the line resistance to low-tension electricity is so great as to render it desirable to make the distance between the firing-machines and fuses as short as possible.

In the year 1851 the author devised a low-tension fuse. A considerable number were made, and used with much success at the Abercarn Colliery, South Wales. These fuses were fired by a Grove battery. In 1862 Bornhardt, of Brunswick, successfully completed his air-tight, high-tension frictional-machine; and some years later Brain, of St. Annals, Cinderford, arranged a frictional-machine. Siemens has also invented a dynamo-

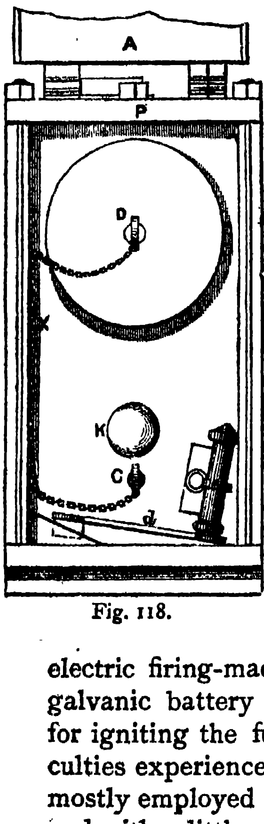

Fig. 118.

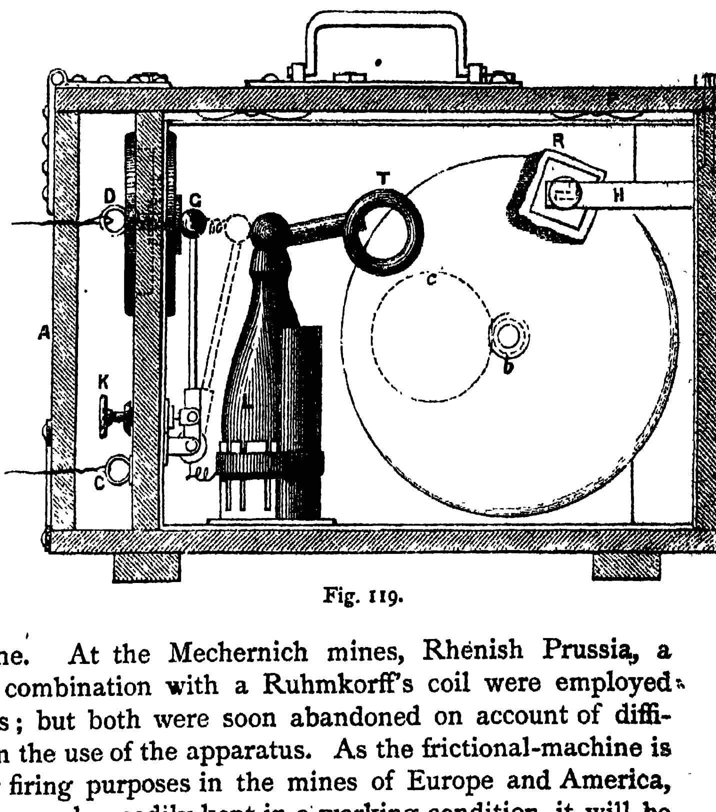

Fig. 119.

electric firing-machine. At the Mechernich mines, Rhenish Prussia, a galvanic battery in combination with a Ruhmkorff's coil were employed for igniting the fuses; but both were soon abandoned on account of difficulties experienced in the use of the apparatus. As the frictional-machine is mostly employed for firing purposes in the mines of Europe and America, and with a little care may be readily kept in a working condition, it will be described, together with the leading wires or firing cables, connecting wires, and fuses.

Firing Machine.—Bornhardt's frictional, air-tight machine is shown in Figs. 118, 119. Fig. 120 gives the outside view with the handle in position for charging the machine. Fig. 119 is a section of the machine showing the internal arrangements, and Fig. 118 is a front view of it with the door open, and the chains attached ready for testing its efficiency. The machine inside consists of a thin ebonite wheel, about 10 inches

diameter, which can be rapidly rotated by turning the handle shown in position in Fig. 120. The top part of the ebonite disc is in contact with the rubber R, Fig. 119, formed of cats-skin, carried by the arm H, and it is by the friction of this skin upon the surface of the disc that the electricity is generated. T shows an ebonite ring, of which there are two, placed opposite one another, and furnished on the inside with metal points being connected with the Leyden jar L, in which the electricity is stored after having been collected from the ebonite wheel by the points in the rings T. C D, Figs. 118, 121, are metal rings projecting through the front of the machine, and it is to these rings that the ends of the wires forming the circuit are to be attached when everything is prepared for firing. K, Fig. 119, is the firing knob by which the electric discharge is made. This knob being quickly pressed causes the arm G to be thrown into the position shown by the dotted lines, thereby making contact with the condenser, completing the circuit, and allowing the charge of electricity stored in the jar to pass along the wires, and in its passage firing the prepared shot-holes simultaneously. In using this machine, a *test* and *firing* operation is necessary. *Test operation:* Immediately inside the door of the machine to the left hand (Fig. 120) are a series of brass-headed nails. At the top and at the bottom of these nails hang brass chains. The hook of the upper chain must be attached to D, Figs. 118, 119, and that of the lower chain to the bottom eye C. The handle of the machine must now be turned briskly ten or twelve times, the knob K, Figs. 118, 119, pressed quickly inwards, when, if the Leyden jar within the box has been fully charged, it will be instantly discharged, the electric fluid appearing as a vivid spark leaping the whole number of nail-heads. These nails are known as the "spark scale." If, however, the electric spark should fail to leap, or to fill up, as it were, the spark scale, the handle must now be turned a greater number of times, not exceeding thirty. If the second trial should fail to obtain a spark of sufficient strength to leap the entire scale, it is a proof that the wheel within the box has become damp, and that it must be dried, either by keeping the box within a warm room a sufficient time for that purpose, or otherwise by taking

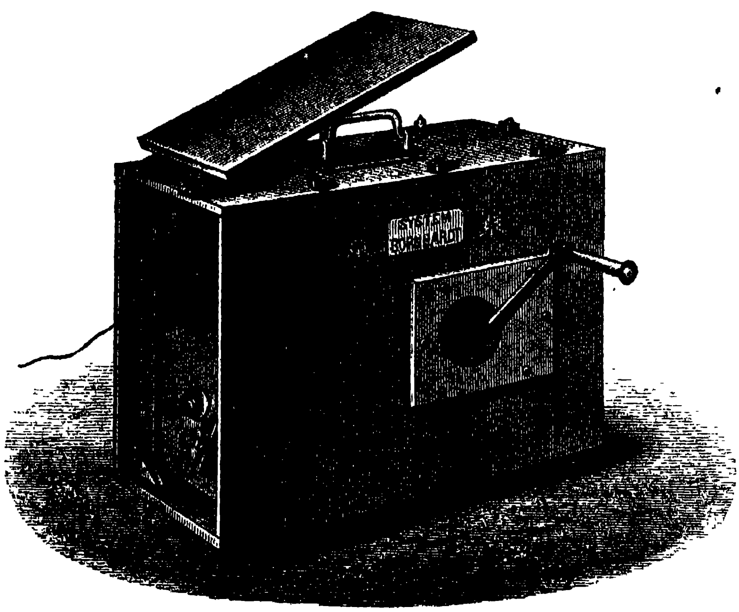

Fig. 120.

off the cover of the box in such room, then drying and wiping the wheel with a dry, warm silk handkerchief in front of a slow fire. Supposing, however, that a strong spark is produced by the testing operation, the chains must be thrown off; and when the fuses are connected together, and the men removed to a place of safety, the leading or positive wire must be attached to the ring D, and the return wire to the bottom ring, so as to form the electric circuit. If now the handle be turned the requisite number of times to produce the full spark, and the knob sharply pressed inwards, a simultaneous ignition of the fuses will occur. To use this machine satisfactorily, it should be sent underground for the purpose of effecting the firing operation, and immediately returned to a warm, dry place. It is essential that the *inside* of the apparatus (viz. the ebonite wheel and cat-skin rubber) must be *kept dry*.

Firing Cables and Conducting Wires.—To insure complete transmission of high tension electricity from the firing-machine to the electric fuses it is necessary to employ conducting wires which are *well* insulated. When the

Fig. 121.

leading wires are subject to rough usage, it is advantageous to form these wires into a cable, protected on the outside with a covering of tarred hemp, or, still better, with a sheathing of iron wire A (Fig. 121). A cable, B, useful in situations where it will not be subjected to any rough usage, consists of two cores or strands, each composed of three tinned copper wires, insulated from each other by two coverings of gutta-percha, or india-rubber and tape, stranded together, and again insulated with gutta-percha, or india-rubber and tape; and lastly covered on the outside with tarred hemp to a diameter of five-eighths

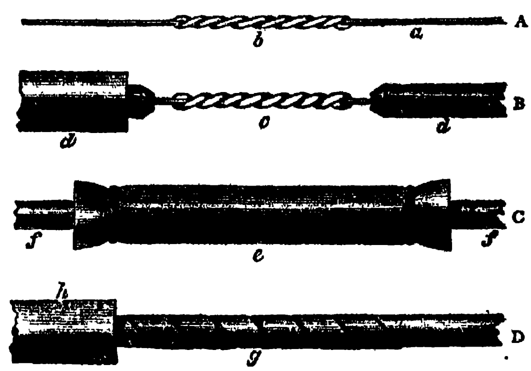

Fig. 122.

of an inch. This cable may be conveniently hung to the roof or sides of a level or shaft, or on poles in open workings. In use it is only necessary to bare the ends of the copper wires in each of the cores, and to connect; viz. two ends, *one* to the positive, the other to the negative pole of the firing-machine; and at the opposite end of the cable and conducting wire, to attach one end to the connecting wire of the *first*, the other to the *last* connecting wire of the electric fuses. In this way the *electric circuit* is formed. Fig. 121, A to E, show in section full-size firing cables of various dimensions, sheathed with wire or guttapercha; F and G guttapercha-covered copper wire, which under certain circumstances

may be used for conveying the electric spark; while Fig. 122, D, shows a cable insulated with tape *g* and guttapercha *h*. To splice an insulated cable it is only necessary to bare the copper wires for a short distance, to scrape them bright, to twist them together, Fig. 122, B, then to insulate the joint with guttapercha, keeping the latter in position by a piece of india-rubber tubing fastened to the cable by wax thread or a piece of fine cord, Fig. 122, C.

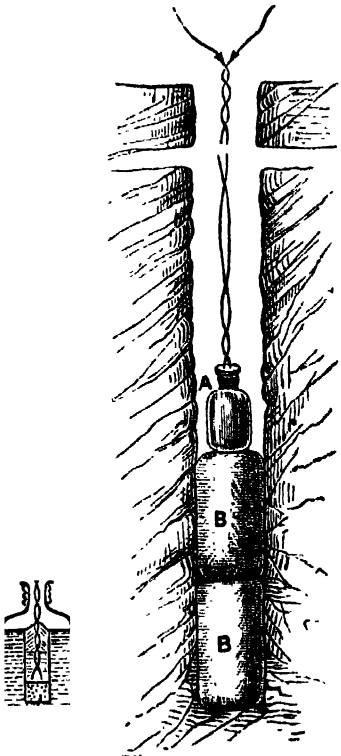

Fig. 123.

Connecting Wires.—These are short pieces of copper wire, shown in section, Fig. 121, G, for connecting the fuses together when the latter are placed in the shot-holes. When the holes are near to each other, and the fuse wires tolerably long, the end wire of one fuse may be directly twisted to the end wire of another, *one* connecting joint being sufficient; but when the fuses are some distance apart special pieces of conecting wires will be required, and two joints between each fuse will be necessary. Fig. 124 shows the wires connecting the fuses lodged in the shot-holes, and Fig. 122, A, the manner in which the wires are twisted together. The ends of the twisted wire should lie on the leading part of the wire. Connecting wires should be kept from touching the rock, as well as from coming in contact with one another. In firing shot-holes placed under water the connecting wires should also be insulated.

Electric Fuses.—An electric fuse consists of a long percussion cap inclosing a fulminating and priming substance, also an insulated wire for conducting the electric fluid. Two kinds of fuses are made, which are known as "quantity" and "tension" fuses. The former are fired by means of a battery, the latter by the application of a frictional-machine.

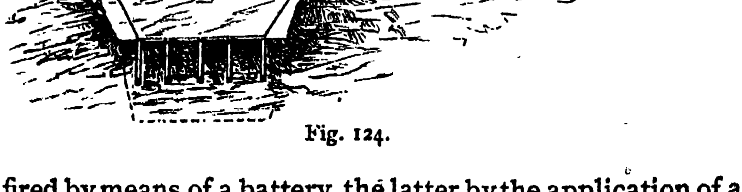

Fig. 124.

The priming or firing composition is placed within a cap, Fig. 123, into which composition the electric wires are imbedded slightly apart from each other. The ignition of the fuse is accomplished in the following manner: The electric spark passes down one wire, leaps from the point of this wire, firing the composition, to the point of the other wire, and passes up the second wire. Fig. 123, A, shows an electric fuse inserted in a dynamite

primer. B, B, cartridges of dynamite laid on a shot-hole ready for electrical firing by the machine.

Firing Operation.—Conducting wires or cables are usually fixed in a level or shaft. As a level or shaft is advanced or sunk, the cables are periodically lengthened, or shifted forward. Between the ends of the cables and forebreast, of a level or bottom of a shaft, two pieces of insulated wire a few yards long are roughly hung. One wire is attached to the *first* wire of the *first* fuse, the other to the *last* wire of the *last* fuse, the intermediate fuses being connected together with short lengths of wire, as already described. The fuses and cable wires being connected together in single circuit—that is, in a line or circle without crossing—the wires at the opposite ends of the cables are attached to the positive and negative hooks of the machine; viz. at C and D, Figs. 118, 119. The handle of the machine is now turned a sufficient number of times to charge the jar, the knob K is then quickly pressed, and the shot-holes, Fig. 124, at the same instant are fired.

Economic Results.—At Ballacorkish, in the Isle of Man, both ordinary and electric fuses have been used, one against the other. In driving the oo-fathom level, the economic value of each kind of fuse has been ascertained. The following are the approximate results—

	Safety Fuse, consecutive blasting.	Electric Fuse, simultaneous blasting.
Number of holes in forebreast	20–24	18–22
Weight of dynamite per lineal fathom	32 lbs.	25 lbs.
Time charging and blasting	30 min.	20 min.
do. clearing gases	45 "	30 "
Saving per lineal fathom of ground		20s.

Mr. Joseph Ball, a practical miner, states: "With safety-fuse the men have often to fire the centre-cut holes *two* or *three* times over, with electric fuses only *once*. The harder the ground, the greater is the saving consequent on the use of electric fuses. With safety-fuse the whole number of holes can only be fired in three operations; with electric fuses two operations are sufficient." Others who have had a lengthy experience in electric blasting, enumerate its advantages over ordinary fuse blasting thus—(1) "It economises capital, time, and explosive material; (2) It is more certain; (3) It is more effective, obstacles are overcome which cannot be removed by the ordinary system of blasting; (4) It is safer, inasmuch as absolute protection to life is secured."

At the Pribram mines, Bohemia, where rock-boring machines are extensively employed in hard, tough, vughy, and jointy rocks, a comparative trial was made—viz. in two shafts, two winzes, and four levels—for the purpose of ascertaining the relative saving which could be effected in the price per fathom, the wages paid per fathom, and the time requisite for driving a fathom of ground by using (1) powder and safety-fuse, (2) dynamite and electric fuses, and (3) dynamite and safety-fuse.

The results are given in the following table—

	Saving per cent. in price per fm. of ground.	Saving per cent. in cost of wages per fm. of ground.	Saving per cent. in time per fm. of ground.
Saving effected by using dynamite and electric fuses over that consequent on the use of ordinary blasting powder and safety-fuse	23	28	33
Saving effected by using dynamite and safety-fuse over that consequent on the use of ordinary blasting powder and safety-fuse	9	11	15
Absolute saving consequent on the use of electric fuses as compared with the use of safety-fuse	14	17	18

The essential points to be observed in electric blasting operations are, to have a reliable fuse, a machine capable of giving a strong electric spark, good conducting cables and insulated connecting wires, so as to ensure the passage of the spark to the fuses included within the electric circuit.

(*l*) *Driving Levels and Sinking Shafts.*—The success attendant on driving levels and sinking shafts by means of machinery is only partly dependent on the boring-machines. These machines now constitute but one of a series of highly important inventions. Had it not been for the construction of efficient air compressors, suitable machine carriages, properly jointed air pipes, the discovery of strong explosives, the development of a new system of arranging the shot-holes, the application of quick charging and blasting these holes, together with *thorough organization of the work*, boring-machines, however good in themselves, would have afforded unsatisfactory results. If a careful inquiry be made as to the rate of boring attainable by individual, but different machines, in one and the same rock, it will be found that, hole for hole, one machine will probably be nearly as effective as the other; that is, if the diameter of the cylinder, velocity of the piston, and width of the tool be fairly equal. A speed of *twenty* fathoms per month, in a level with *four* boring-machines, is no greater in the *boring result* than one of *ten* fathoms per month accomplished by means of *two* machines. The work per borer may be regarded as equal, although the speed of the advance in the former case is doubled.

Although it will be desirable to adduce examples of quick and average results attained, both in driving levels and sinking shafts, yet it must be observed that no definite idea can be formed of the value of the circumstances which enabled the speed of one operation to be rendered sensibly greater than that of another. The relative hardness, position, and character of the rocks must be known; the conditions which aided or retarded the work, correctly understood; the nature of the manual and mechanical power which had been employed must be ascertained; these, and perhaps other important details, may have to be adjusted one with another so as to arrive at any just conclusions on the subject.

Organization and Conduct of the Work.—In driving levels or sinking shafts with the aid of rock-boring machinery it is necessary to conduct the operation in some special manner.

The appliances necessary at the forebreast of a level will in a measure depend upon the number of machines to run together. If only one machine, a simple vertical or horizontal bar will suffice; if two machines, two vertical bars braced together at the bottom, or a vertical bar carrying two horizontal bars. For running four or six machines together, heavy carriages will be desirable. The driving of a heading may be classed under—

High tunnel speed,	requiring from	40 to 50 hands.
High level speed,	,, ,,	12 to 24 ,,
Moderate level speed,	,, ,,	6 to 9 ,,

At St. Gothard (Airolo), where high tunnel speed was a necessity, and sixteen or eighteen men employed together at the forebreast, the appliances consisted of—

A carriage, weighing several tons, carrying six boring-machines.

A cylindrical reservoir, set to the rear of the boring-machine carriage, for delivering water to the holes.

A waggon placed to the rear of the water reservoir, for holding and running the tools to and from the forebreast.

Fig. 125 shows this arrangement in plan. The depth of cut is indicated by dotted lines in advance of the heading; the position of the holes by angle-dotted lines; and that of the workmen by the small crosses. Thus there is one man to each boring tool, three men to the machines, one man in attendance on the air and water supply, one man at the tool waggon, and one foreman stationed at the coiled portion of the air pipe.

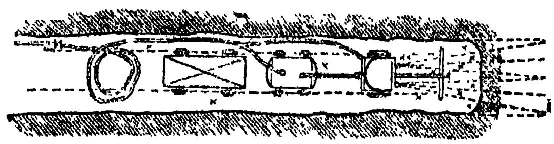

Fig. 125.

In Belgium, where Dubois and François have arranged various sets of apparatus for driving ordinary mine levels at a high speed, the driving plant, handled by four or five men per shift, consists of—

A carriage on which is mounted three or four boring-machines.

A cylindrical reservoir, to the rear of the carriage for supplying the holes with water.

An electric cable.

Where the drilling appliances are arranged to suit the conditions incident to the waggon and drawing ways, and to be handled by two or three men per shift, the plant may include—

A small wooden trolley and stand, on which two machines are mounted.

A small pipe for conveying water to the holes.

An electric firing cable.

When rock-boring machines were first introduced the miner insisted on employing them as mere substitutes for the borer and the mallet, and upon placing the holes so as to "take advantage" of the ground. The result, however, proved unsatisfactory. Not only was the time required to get a position for the machine, to fix, and to remove it, excessive, but the work accomplished was not in proportion to the cost. The engineers of the Mont Cenis Tunnel were the first to recognise the fact that, if power machines were to be employed for drilling shot-holes, the hand method of working the ground must be discarded. A given number—ten machines—were thereupon mounted on a carriage in such a manner that *each* could perforate a *given area* of the face. The natural rupturing lines of the rock were disregarded, deep shot-holes were drilled, charged, and blasted, and in this way a definite length of ground was removed. In France and Belgium this length of ground is known as an "avance," in some parts of England and America as a "cut" or "spell," while in shafts it is properly designated a "sink." The divisions into which the entire operation of a "cut" or "sink" is apportioned are as follows—

(*a*) Boring shot-holes { 1 Circular cut system.
2 Square-cut "
3 Radial-cut "

(*b*) Charging and blasting the holes.

(*c*) Removing the stuff.

other. C and D are holes placed respectively 4 and 6 inches from the middle of the centre hole, each 6 feet deep, angled so as to *diverge* slightly from the centre hole. E F G H are a series of short holes, each about 3 feet deep, angled as shown. Around the 10 centre holes are 22 additional holes. In blasting by electricity the holes B C D G are first fired, then the shorter holes. If safety-fuse is used, the firing commences with the hole B.

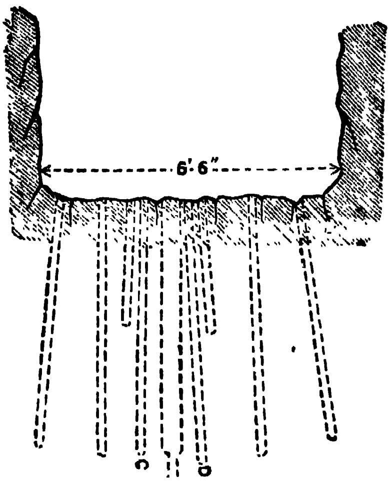

Fig. 130.

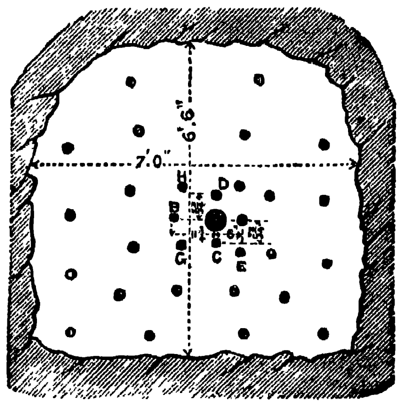

Fig. 131.

Figs. 132 and 133 show number and position of holes in a face of hard rock 7 feet wide by 6½ feet high, as arranged by Dubois and François. The holes, A B C D, four in number, angled towards the axis of the level, are bored within a circle 12 inches diameter. The second circle, placed about a foot outside of the first circle, contains 6 holes almost in line with the axis of the level. The third circle, distant a foot or thereabouts from the second

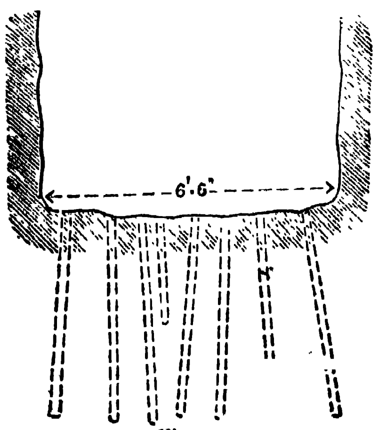

Fig. 132.

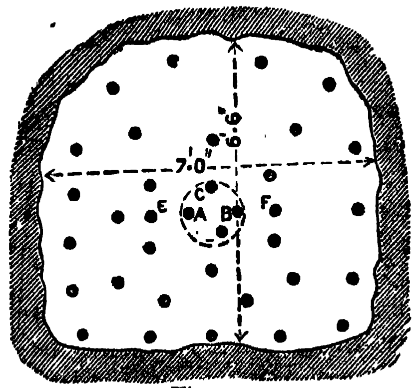

Fig. 133.

circle, has 7 holes, each angled slightly *from* the axis of the level, while the last or outer circle includes 16 holes, strongly angled *towards* the roof, the sides, and bottom of the level. Altogether, in a face of rock containing 45 square feet, 33 holes are bored, each about 4 feet deep.

In a level recently driven at Carn Brea, 4 converging holes were drilled around the axis of the level, then other 12 outside holes, making a total of

16 holes in a forebreast 7′ × 7′, giving an area of 49 square feet. The average depth of these holes was 42 inches; time of drilling 16 to 18 holes with four machines, from four to five hours, or about one hole per machine per hour, equal to a shift rate of $\frac{7}{10}$ of a lineal inch per minute. In this rate is included the time requisite for the introduction and withdrawal of the boring-machine, carriage, angling the machines, and changing the tools. At Maesteg, the heading in grit rock, 8 × 8, giving an area of 64 square feet, was perforated with 16 or 18 holes, $3\frac{1}{2}$ to 4 feet deep, in about four hours. The holes were commenced with bits $2\frac{5}{8}$ inches, and finished with bits $1\frac{1}{8}$ wide. In the hard rock five bits were ordinarily required, in the soft rock three sufficed to complete the hole. Careful judgment was exercised in drilling the holes at the angle most effective for the ground to be blasted. The top holes were generally set to rake upwards, the lower holes downwards. In this case the boring result per machine was 48 inches per hour, making a shift rate of $\frac{8}{10}$ of an inch per minute.

The method of sinking by the "circular-cut system" was introduced by Darlington at the Minera mines, North Wales, and at the Ballacorkish mines, in the Isle of Man. The engine-shaft at the latter mine is $10\frac{1}{2}$ feet diameter. A centre or rupturing hole was dispensed with. Four holes, each about $3\frac{1}{2}$ feet deep, were bored so as to converge sharply towards the centre. Around these, the centre cut holes, two sets, including 20 holes, each 4 feet deep, were bored. When necessary the 4 centre holes, Fig. 134, were from $1\frac{3}{4}$ to 2 inches diameter, the other or outside holes, $1\frac{1}{4}$ inch diameter. At Ballacorkish the four centre holes were first electrically fired, then the holes in the second circle, and lastly the whole of the outside holes.

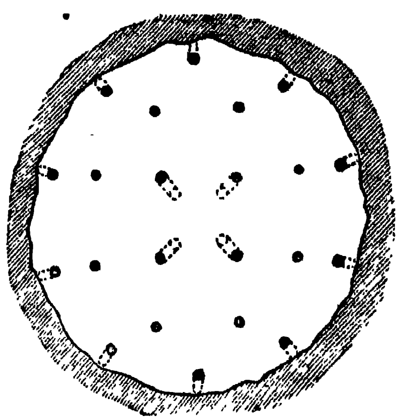

Fig. 134.

Square-Cut System.—The "square cut" system was first developed at the Hoosac Tunnel in America, about the year 1866, and perfected in driving the Musconetcong Tunnel, six or seven years later. Mr. Drinker, in his able work on "Tunnelling," thus describes this system: "At first $3\frac{1}{2}$-inch and then 4-inch drills were tried, but finally the 5-inch was decided on, as by far the best size in the hard rock encountered. The drills were mounted in the heading on two carriages, one on each side of the centre line. These carriages were simply frameworks of oak, running on rails carried up to the face of the heading. Fig. 133 shows a plan of the fore part of one of these carriages, there being two in the heading, one on each side. After a blast, all hands were at once engaged in shovelling and filling the broken rock into the middle of the tunnel, between the machine rails, so as to clear the latter. As soon as the way was clear, the carriages were at once run up to the face and drilling recommenced, and the broken rock subsequently removed in waggons running on the centre way.

"The heading being 26 feet wide, there was room enough to accommo-

date the three roads, and by proper switching there was rarely any detention from want of waggons. The method of blasting by cuts is based on the extraordinary force developed by a comparatively small bulk of explosive matter.

"It consists in first blasting out an entering wedge or core about 10 feet deep at the centre, and subsequently squaring up the sides by several rounds; to do this twelve holes are drilled by the six machines, three sets on a side, the holes placed as shown in Fig. 136, and marked *c*, A, being the floor of the heading. These twelve holes are drilled two and two, six on a side, with from $1\frac{1}{4}$ to $2\frac{3}{4}$ inch bits, the two sets being started about 9 feet apart, and at such an angle as to meet or cross at the bottom, the largest bits being put in first.

"They are then charged with about 25 lbs. No. 1 and 50 lbs. No. 2 dyna-

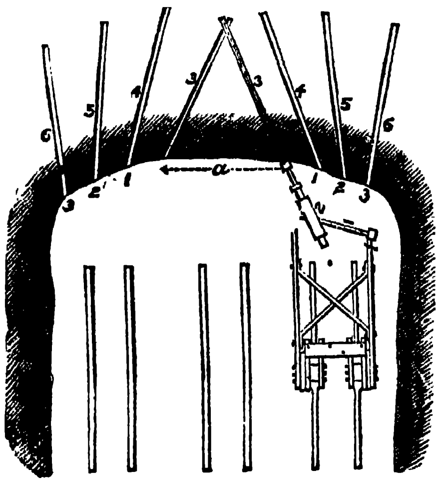

Fig. 135.

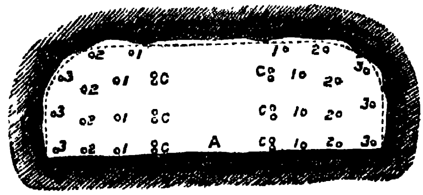

Fig. 136.

mite, and fired simultaneously by electricity. No. 1 dynamite is only used for cuts, inasmuch as in them a quick, strong explosive, comprised in a small bulk at the bottom of the holes, where the greatest resistance will be found, is required; while No. 2 dynamite added serves in filling the holes, so starting the sides of the cut as the apex is moved. The cut being out, a second round of holes is started for the first squaring up, as shown by the Nos. 1, 1, 1, 1.

"In these, and in the subsequent rounds 2, 2, 2, 2 and 3, 3, 3, 3, the resistance is equally distributed along the whole length of the holes, and is also not so great as in the cut; therefore No. 2 dynamite is used, as in it the nitro-glycerine being mixed with a larger proportion of absorbent matter, the force is thereby distributed over a greater space.

"In the first and second squaring-up rounds from 50 to 60 lbs. of No. 2 dynamite are charged, and in the third from 80 to 90 lbs., the holes getting stronger as the arch falls at the side. There are also generally one or two additional roof holes in the third round that are not shown in the figure, their position being variable according to the lay of the rock. The top holes in the first round are also designed to bring down any roof not shaken by the cut, and are therefore given a strong angle towards the centre, and always drilled from 12 to 14 feet deep.

"The horizontal projection of the above holes is shown in Fig. 135, 3 being the centre cut holes, 4, 5, and 6 the squaring up rounds.

"As to their relative depths, the holes of the first squaring rounds are

always drilled a foot or more deeper than the cut holes, and when blasted they generally bring out a foot additional of shaken rock at the apex of the cut. The following table approximately shows the number and depth of holes required, and the dynamite used for a lineal advance of 10 feet of heading work:—

	No. of holes.	Depth of holes in feet.	Total depth of holes in feet.	Dynamite used. No. 1.	Dynamite used. No. 2.
Cut, or centre wedge	12	$10\frac{1}{2}$	126	25	50
1st square up	8	12	96		55
2nd do.	8	12	96		55
3rd do.	6	12	72		85
Roof holes	2	10, 8	18		
	36		408	25	245
			Total	270	

"Now allowing the cut holes to be $10\frac{1}{2}$ feet deep, the cut will generally blast about 9 full linear feet. Assuming the average cross section—width 26 feet, height 8 feet—to be about 175 square feet for a lineal advance of 10 feet, 65 cubic yards of rock would be broken, which would give an average of say four-tenths of No. 1 and four pounds of No. 2 dynamite consumed to the cubic yard of rock, and a little over 6 feet of hole drilled per cubic yard broken." As to the division of time, it took one shift to drill and blast the cut, and one shift to each of the three rounds, making a period of twenty-four hours. The work was effected with a force of twelve men per shift, or forty-eight to the pare; viz. one driller and one helper to each machine; together four men, six trammers, one assistant carrying tools, and one foreman. The square-cut system has been adopted in driving headings at the Minera mines, North Wales, and at Ballacorkish, in the Isle of Man. At the former mine, in cherty, drusy Limestone 200 yards below the surface, a cross-cut $6\frac{1}{2}$ feet wide by $6\frac{3}{4}$ feet high was driven by means of two machines mounted on a stand. One machine was at work while the other was being arranged for boring another hole. The shot-hole at top was $1\frac{3}{8}$ inch, and at bottom $1\frac{1}{8}$ inch diameter. Owing to the "short jointy" nature of the rock, deep holes could not be carried without incurring a heavy cost for dynamite —a cost disproportionate to the gain acquired in speed. The following figures give the number of holes, total depth, and weight of dynamite used for a cut of 2 feet 9 inches:—

	No. of holes.	Av. depth of holes.	Total depth of holes.	Dynamite consumed.
Cut	10	3	30	12–13 lbs.
First square up	8	$2\frac{3}{4}$	22	
Second do.	8	$2\frac{3}{4}$	22	
Roof-holes	2	3	6	
	28		80	

At Ballacorkish the heading, $6\frac{1}{2}$ feet wide by 7 feet high, was driven partly in the country and partly in the lode.

The country rock was composed of short-jointed Clay-Slate, the lode of quartz, and various other minerals of different degrees of hardness, frequently enclosing vughs, or openings. The end was perforated with seventeen or eighteen holes of an average depth of 44 inches, and a bottom diameter of $1\frac{1}{8}$ inch. The time required for drilling the holes with two machines,

including fixing and removing the stand, shifting the machines, and changing the tools, was from seven to eight hours. Number of holes per machine, $1\frac{1}{4}$ per hour, or a shift speed of $\frac{9}{10}$ of an inch per minute.

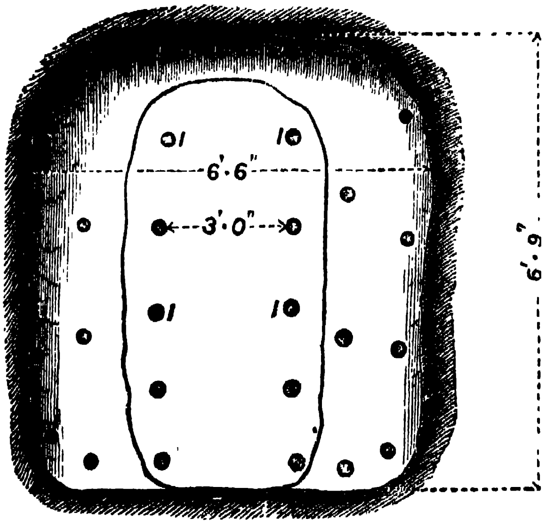

Fig. 137.

Minera Mines.—Fig. 137 represents the face of a cross-cut in this mine driven with two Darlington machines. Height of cross-cut, $6\frac{3}{4}$ feet; width, $6\frac{1}{2}$ feet; area of face 40 square feet; number of holes in heading, 26 to 28; average depth of holes, 34 inches; diameter of holes at bottom, $1\frac{1}{8}$ inch; area of face to one machine, 20 square feet.

Cut	10	holes each,	3 ft.	deep.
First square up	8	,,	$2\frac{3}{4}$	,,
Second do. .	8	,,	$2\frac{1}{4}$	,,
	26			
Roof-holes .	2			
Total	28			

Cut electrically blasted as follows: (1) Cut or centre, 10 holes; (2) First square up, 8 holes; (3) Second square up and roof-holes, 10.

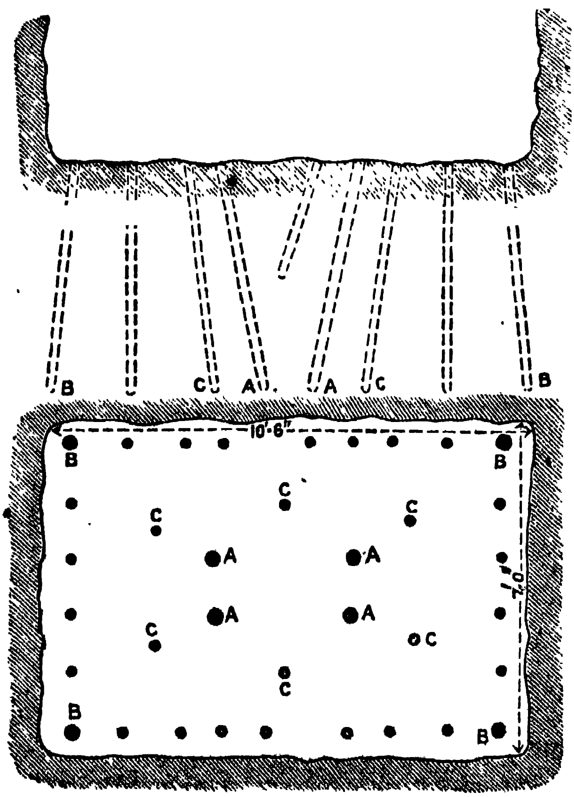

Fig. 138.

Mixed-Cut System.- This system is in use at Ballacorkish, in the Isle of Man. For particulars and illustration, see page 554, Fig. 142.

In sinking pits Dubois and François have resorted to a system of shot-holes of large and small diameters, and combined the square with the circular-cut system. Fig. 138 represents a plan of a shaft, together with the position of the various holes.

The holes, each $4\frac{3}{4}$ feet deep, are angled, as shown in the vertical section. The four central holes, A A A A, as well as the corner holes, B B B B, are $1\frac{3}{4}$ inch diameter, while the other holes are $1\frac{1}{4}$ inch diameter at the bottom. The number of holes in the bottom of a shaft $10\frac{1}{2}$ feet long by 7 feet wide are eight $1\frac{3}{4}$ inch diameter and twenty-eight $1\frac{1}{4}$ diameter. The holes are electrically blasted,

the first volley being the four centre holes, then the six outside holes, and lastly the perimeter holes.

Radial-Cut System.—Mr. W. Blanch Brain, of St. Annals, Cinderford, when driving a level at the Drybrook mines, employed a horizontal stretcher bar, and fixed it in such a position with the height of the level and the length of the machine as to perforate the face, by simply radiating the machine on the bar for drilling the shot-holes on a vertical line at the requisite angles, and shifting the machine on the bar to repeat the boring operation. This Mr. Brain designated the "radial system."

Fig. 139 shows the sectional form of the Drybrook level, the disposition of the holes, and the line of the electric cable for obtaining the cut. Rock—dolomite—width of level, 6 feet; height, $6\frac{3}{4}$ feet; area of heading, 40 square feet; number of holes in heading, 34; depth of holes, 3 feet to 4 feet 3 inches; diameter of holes at bottom, $1\frac{1}{4}$ inch. The rock removed by the first blast included the portion between the bottom and upper cable line; the second blast, that between the upper cable line and the roof.

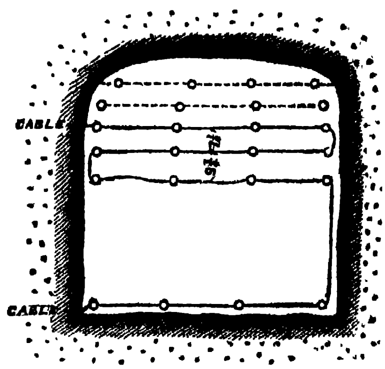

Fig. 139.

Observations.—The form and character of rock-boring machines, together with the method resorted to for mounting them, render it necessary that the circular, square cut, or a combination of these two systems, should be employed for the purpose of effecting the removal of the ground, both in levels and shafts. No diagram of the holes, which may seem to be necessary for obtaining a cut or sink, can be advantageously followed. A clever miner will take advantage, it may be a limited one, of faces, joints, and lie of the ground, so as to minimise the number of the shot-holes and weight of explosive necessary. He will bore the shot-holes as deep as possible, or, in other words, as deep as the explosive is likely to produce a satisfactory result, so as to quicken speed and lessen the dead cost; he will seek to get out his cut, or wedge, in a part of the face where the resistance is least; and acquaint himself fully with the mechanical conditions of the machines, and the stands to which they may be attached. The general tendency of recent practice is to bring into use larger machines for boring; to increase the diameter of a part, if not of the whole of the shot-holes; to lessen the number of holes in a given area of rock, and to employ a greater proportion of dynamite per hole.

At Musconetcong the centre wedge was removed by a series of *double* shot-holes; that is, two holes were bored side by side and heavily charged with No. 1 dynamite, while the sides, or square up cuts, were removed by the use of No. 2 dynamite. The Mont Cenis engineers bored an axial or central hole, and clustered around it other shot-holes, converging towards the line of the centre hole. The centre hole was not charged with powder, but the outside ones were heavily so, and when fired broke out the centre of the face, so that the surrounding rock presented the form of a cone. Dubois

and François greatly extended the use of this method; but of late these engineers, doubtless through their wider experience, have in some instances modified their practice, and resorted to a mixed system of large and small holes, placing the former on the line of the greatest resistance.

At Ballacorkish, where from the peculiar and variable character of the ground the centre-cut holes, eight in number, were placed below the normal axis of the level, while the cuts were made from roof to sole, rather than from side to side of the level. In this case, as in almost every other where ground is irregular in its character, the centre-cut is best made in a part of the face where resistance to the rupturing strength of the explosive is least, while the surrounding holes should be so placed as to help each other in the blasting operation.

The rate of speed which may be obtained in boring is not to be measured by one drill running against another; but it must include the time requisite for fixing and shifting the machine, changing tools, and attending to other details, some of which will be incident to one machine and not exist in connection with another. This may be distinguished as the "shift speed."

Further, the length and constructive character of a machine will affect the angling range, and entail consequences of a pecuniary character. If the angling range be low, that is, almost parallel to the side of the level, a greater weight, or a stronger explosive, will be necessary for shifting the ground than if the holes were more sharply inclined towards the face.

TABLE I.

APPROXIMATE SHIFT RATE OF BORING SHOT-HOLES IN VARIOUS ROCKS BY SUNDRY BORING-MACHINES, INCLUDING IN THE SHIFT THE TIME REQUISITE FOR FIXING AND WITHDRAWING BORING TACKLE, SHIFTING BORING-MACHINES, CHANGING TOOLS, AND DRILLING THE HOLES.

Name of Place.	Name of Machine.	Diameter of Boring Machine Cylinder in Inches.	Diameter of Shot-hole at Bottom.	Shift Rate of Boring Shot-hole per Minute.	Rock.
				Inch.	
Musconetcong	Ingersoll	5	1½	1·20	Syenite.
Minera	Darlington	2¾	1⅜	1·00	Tough Limestone.
Maesteg	Beaumont	4	1½	1·00	Pennant Sandstone.
Portskewet	Geach	3½	1⅜	0·90	Pennant Sandstone.
Cwmbran	McKean	4	1¼	0·80	Pennant Sandstone.
Dolcoath	Barrow	4	1⅜	0·80	Hard silicious tin lode.
Marihaye	Dubois François	2¾	1½	0·80	Sandstone and shale.
St. Gothard	Ferroux	3¼	1⅛	0·80	Granite and gneiss.
Laxey	Ingersoll	2½	1⅜	0·80	Hard Killas and spar.

NOTE.—The comparatively high shift rate of boring obtained at Musconetcong was due partly to the great power of the drills, and partly to the circumstance that the cut-holes were nine feet deep, giving a larger proportion of time to the boring operation than is obtainable when ordinary three-feet cuts are made. In the latter case, the tackle must be shifted three times to obtain an advance of nine feet, whereas in the former case it was only shifted once.

Charging and Blasting.—Holes bored by machine drills cannot be placed in accordance with the line of least resistance. To compensate in some degree for this defect incident to machine work, the strength of the charges should be varied according to the resistance which they will be required to overcome. The holes for unkeying the face will require the

heaviest charge of explosive material, since the conditions for getting out the cut or wedge are usually most unfavourable for the power of the explosive. The quantity of explosive for each hole must vary greatly, since it will be dependent on the nature of the rock and the resistance offered to the blast. The proper charge can only be ascertained by experience. If holes are fired singly more dynamite will be required than if fired simultaneously. For taking out the wedge or centre-cut the strongest dynamite should be used. For enlarging the face around the wedge or centre-cut No. 2 or 70 per cent. nitro-glycerine dynamite will often prove strong enough. In Schist, and Sandstone rocks of a bedded character, good results have been obtained by the use of cartridges of compressed powder ignited at the bottom. (See elevation and plan, Fig. 140.) At Ronchamp, in France, dynamite and powder exploded together gave excellent results.

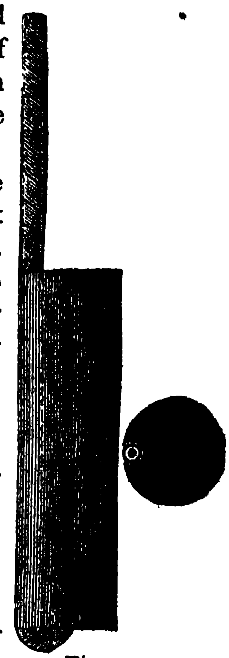

Fig. 140.

It was held that the powder prolonged, as it were, the time of the explosion, and exerted its force on the rock weakened by the quicker rending strength of the dynamite. At Musconetcong the strongest dynamite, containing 75 to 77 per cent. of nitro-glycerine, was employed for unkeying the face, the square-up or side cuts being subsequently removed with dynamite of lesser strength.

At St. Gothard very deep holes were tried; but in many instances it was found that "sockets" were left after the holes were blasted. By giving the holes a greater diameter this drawback was materially abated. As, however, the consumption of dynamite was found to be large, it was afterwards used surrounding a cylinder of clay. In this way the weight of explosive was said to be sensibly lessened without decreasing to a proportionate extent the measure of the result. To obtain a maximum effect from the detonation of dynamite it should be placed at the bottom of the shot-hole, and confined by water, or otherwise gently tamped with about three inches of soft clay. Many miners assert that tamping is unnecessary. The fact is, it is not so essential a matter with quick-rending explosives as with black powder. In the one case the liberation of the expansive gases is instantaneous, in the other it is gradual; but with any explosive the complete confinement of the gases *must* increase the effect. The filling up of any space around the charge is also important. Experiments conducted in America for ascertaining whether a small space between a ball and a charge at the bottom of a mortar would have the effect of lessening the distance to which the ball would be thrown, showed that with a quarter ounce of No. 2 dynamite, which constituted each of the charges, the loss was very great.

Expt.	Ball raised from Bottom of Charge in Mortar.	Thrown.	Loss.
No. 1	0 0 inch	630 feet	
2	0·05 „	579 „	51
3	0·10 „	550 „	80
4	0·20 „	490 „	140
	0·40 „	440 „	190
	0·60 „	400 „	230
	0·80 „	350 „	280

If water be employed for tamping purposes, the detonators attached to the fuse should be protected so that no water can enter between the fuse and the detonator to interrupt the igniting operation. Even if the fulminate should become damp this circumstance alone will materially lessen the power of the fulminate, and, perchance, cause the dynamite to burn, losing thereby its money value, as well as its disrupting effect. The order of firing the shot-holes should be determined at the time of charging and tamping them. Naturally such holes should be selected as will rupture and unkey the rock to the desired depth, and which will also secure the most effective results on firing the second set of shot-holes. When successive series of holes are to be fired by means of safety-fuse, the length of the fuses may be regulated, if necessary, so as to effect the discharge of certain holes earlier than that of other holes. If also the ends of the fuses be brought together, their ignition may be accomplished at one and the same time. This may be effected by inclosing the ends in a small powder cartridge, and firing the latter by a short piece of safety-fuse.

Ventilation.—Immediately after blasting a set of shot-holes any noxious gases resulting from the explosion should be quickly removed.

To effect this object compressed air may be discharged from the air-pipe close to the forebreast. The air for ventilating purposes need not be highly compressed, the pressure of a single atmosphere will suffice. If air under a pressure of three or four atmospheres be used, and steam employed for compressing it, the cost of fuel will prove to be unnecessarily high. At St. Gothard large exhaust-bells were erected for withdrawing the vitiated air from the headings; but sixteen compressors in action were found to afford sufficient air for aeration and for boring operations. At Cwmbran, South Wales, a large fan, in connection with wooden trunks 12 inches wide and 30 inches high, was used to exhaust the air from the heading. At Portskewet the foul gases were withdrawn from the heading through zinc pipes 12 inches diameter. At Ballacorkish these gases were blown from the 60-fathom level forebreast, an air cock being left open for that purpose previous to firing the shot-holes.

Removal of Stuff.—Before blasting it is desirable to lay down in front of the face a piece of sheet-iron, so as to enable the men to shovel the stuff more readily into the waggons. When a double railway is laid in the level one waggon may always stand empty at or near the forebreast, while the other is in course of filling; but where a single way is laid it is desirable either to have a loop or shunt not far distant from the forebreast, so that the loaded waggon may be quickly removed and replaced by an empty one. In the sinking of the Ballacorkish and Minera shafts, the main drawing kibble was invariably sent from the surface to the bottom. In the former instance a wrought-iron pent-house was always directly over the heads of the men, to protect them from the fall of a stone or other substance. A simple way of quickly withdrawing the stuff from shafts, fitted to a given depth with a skipway, is by means of an hydraulic or pneumatic winding engine. The former might in many cases be driven by a small two-inch pressure pipe attached to the upper part of the pump-work. For every 50 fathoms of vertical height the pressure may be reckoned at 125 lbs. per square inch.

A water pressure of 700 or 800 lbs. per square inch may he satisfactorily employed. If pneumatic engines are used the air should be worked expansively, and the heat extracted from the air during its compression, partly restored to it during its expansion within the cylinder, viz. by contact with a finely-divided spray of water delivered as warm as it can be obtained. A compact and useful pneumatic engine devised for underground hauling purposes is shown in Fig. 141. The cylinders are 6 inches diameter and 10 inches stroke, drum 27 inches diameter, geared 6 to 1. With 40 lbs. of air the engine will rapidly lift a load of 1,500 lbs.

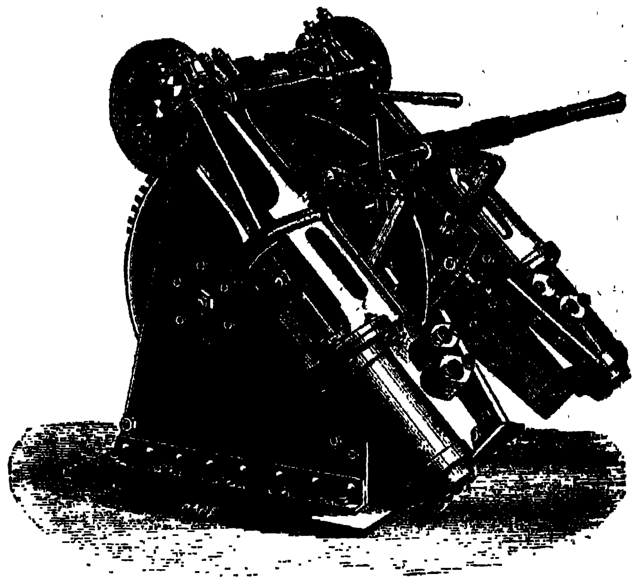

Fig. 141.

Time and Speed.—The time occupied in completing a cut of ground will in effect summarise the speed of the various operations. In boring the shot-holes a specific portion of time is required for—

(*a*) Introducing and fixing the boring-machine frame.

(*b*) Boring shot-holes { Angling and shifting the machines. Changing boring tools. Boring holes.

(*c*) Unfixing and withdrawing the boring-machine frame.

The time requisite for the introduction and withdrawal of the machine frame (*a* and *c*) may be taken as a constant factor; that is, the time of the operation incident to one and the same apparatus will not vary, whether the apparatus may carry one or four boring-machines. In the matter, however, of boring the shot-holes with one or four machines, the time will not vary in inverse proportion to the number employed, but it will diminish in an increasing proportion with an increase in the number of the machines.

One machine perforating an entire face (7 feet × 7 feet) giving 49 square feet, must be shifted to the requisite parts of this face, admit the change of tools necessary for running down the whole number of holes, and must therefore be charged with the entire amount of time necessary for shifting the machine and changing the tools.

Four machines employed on a face will divide it into quarter sections. If twenty holes, each 3½ feet deep, are necessary for the cut, it follows, *one* machine will operate on an area of 12¼ feet, and run down five holes.

To bore twenty holes, 3½ feet deep, *one* machine must be angled and shifted at least twenty times. If three tools are required per hole, sixty tools must be changed to bore the twenty holes.

The time incident to shifting or angling a machine so as to command a fresh hole, and to changing the tools for boring the hole, cannot be fairly reckoned at less than two minutes, consequently the time imposed on one machine per cut of ground is—

Introduction and withdrawal of the machine, say	30 minutes.
Shifting and angling machine (20 × 2)	40 „
Changing tools (3 × 20 × 2)	120 „
One machine	190

Now if *two* machines be employed it is obvious that the time of shifting and changing the tools, 160 minutes, will fall on two machines, or 160 minutes will be represented by 80 minutes.

Tabulated on one, two, and four machines, the result will be—

	No. of Machines. One.	Two.	Four.
Introduction and withdrawal of machine frame	30 min.	30 min.	30 min.
Shifting and angling machine	40 „	20 „	10 „
Changing tools	120 „	60 „	30 „
Relative time necessary	190	110	70

Thus by the concurrent application of *four* machines to the face, the gain in time in the boring operation over the use of *one* machine is about sixty-three per cent. In other words, *four* boring-machines, to make *three* cuts of ground, will only abstract from the boring period as much time as will be required in the application of one machine to make *one* cut. A high boring speed is therefore attainable by dividing and distributing the various operations of delay over *two*, *four*, or *six* machines, instead of imposing them on *one* machine.

In the charging and blasting operations time can only be saved and speed acquired by observing the following general rules:—

On the completion of the boring operation let the cartridges be prepared so as to place them directly into the holes to be fired.

If the holes are to be electrically fired, let one or both of the wires be of sufficient length to form *one* instead of *two* mechanical connections between two fuses.

Fire a maximum number of shot-holes together, and dislodge the cut in at least two firing operations.

As it may be assumed that the time required in each blasting round, apart from the charging and firing process, viz. for the removal and return of the workmen to their positions, and for exhausting the gases from the face, will not be ordinarily less than ten minutes, it follows that if four firings are made per cut, the aggregate time will be forty minutes; whereas if it be two firings, the time will be reduced to twenty minutes.

In the removal of the stuff a similar necessity exists to do the work quickly; that is, if a maximum speed of drivage is to be obtained. The obvious rule for observance is to remove the stuff just a sufficient distance, or in such a manner, as to get the machines to the forebreast in the shortest time possible so as to commence a fresh cut. If the machine men have to "waggon the stuff" to such a distance that they can only get rid of four tons per hour, and other arrangements are practicable by which the forebreast can be relieved to a threefold extent in the same time, then the stuff yielded

by a $3\frac{1}{2}$-feet cut in a forebreast 7 feet × 7 feet would be roundly 16 tons, while the gain in time would amount to 66 per cent.

Thus:	16 tons	at 4 tons per hour	=	4	hours
	16 „	12 „		$1\frac{1}{3}$	„
		Gain per cut		$2\frac{2}{3}$	= 66 per cent.

It is therefore evident that a high-speed result is consequent on running several boring-machines together, executing each operation quickly, shortening the period of such delays as may bear on the actual boring, charging and firing of the hole, and on instantly ridding the face of dislodged stuff, so as to introduce the machines for a fresh attack.

The approximate length of time required (1st) to bore the shot-holes with four machines, (2nd) to charge, blast, and remove the stuff, has been tabulated by Messrs. Dubois and François as follows:—

Character of Rock.	Proportion of Time employed in boring the Shot-holes with Four Machines.	Proportion of Time employed in blasting and removing the Stuff.
Soft schist	0·30	0·70
Hard schist	0·35	0·65
Ordinary gritstone	0·40	0·60
Hard gritstone	0·50	0·50
Hard gritstone and quartzite	0·65	0·35

WORK EXECUTED.—The works executed in this country with the *Darlington rock-boring machines* fall within the class of moderate level-driving speed. In every case only two boring-machines have been worked together, while the number of men employed per shift has frequently been two, and never more than three, or six or nine men to the "pare." In addition the men have usually had to tram the stuff to the shafts, and in one or two instances to place it in the kibble. These operations are in a sense outside hindrances to the normal speed which should be acquired in the use of such machines. At Ballacorkish, in the Isle of Man, the engine-shaft, $10\frac{1}{2}$ feet diameter, was sunk by twelve men at the rate of about 2 fathoms a week. The time occupied in the three distinct operations—

(1) Boring the shot-holes,
(2) Charging and blasting them,
(3) Removing the stuff—

was as follows:

Boring shot-holes	184 hours or	20 per cent. of total time.	
Charging and blasting	94 „	10 „	„
Removing stuff	$666\frac{3}{4}$ „	70 „	„
	$944\frac{3}{4}$	100	

The weight of dynamite consumed was 329 lbs., which removed 704 tons of rock.

Dynamite consumed per lineal fathom of ground	$23\frac{3}{4}$ lbs.
„ „ cubic yard of ground broken	$1\frac{4}{10}$
„ „ ton of ground	$1\frac{1}{4}$ „
Lineal feet of shot-holes made per cubic yard of rock	$8\frac{7}{10}$ „
Average depth of holes per cut	52 inches.
Average depth sunk per cut	46

The men who conducted the work were taken direct from the tribute pitches, and at the end of a 20-fathom contract were sinking at the rate of 2 fathoms a week, although an 8-inch pump 23 fathoms long had become very heavy to handle, and the drawing appliances were altogether below the capacity and speed requisite for a quick dispatch of the work. The rate of

speed at which the shaft was sunk was five-and-a-half times quicker than could have been accomplished by hand labour alone. The hand price for the shaft was £31 10s. per lineal fathom; the machine price £13, which included the cost of coal for the compressor. On completing the engine-shaft to the 60-fathom level, a plat was first cut by means of the boring-machines; second, a long cross-cut driven to the lode; thirdly, a level 6′ 6″ wide by 7′ 0″ high extended partly on the lode and partly in the country for a length of 150 fathoms.

Nature of Ground.—The ground through which the level was driven for the length referred to consisted of tough, jointy Clay-Slate, occasionally varied with quartz, forming two-thirds of the width of the end, then the lode itself inclosing quartz, blende, lead, patches of slate, vughs, and joints.

The boring-machines employed were two in number—single acting, with an effective pressure equal to a cylinder $2\frac{5}{8}$ inches in diameter.

The number of blows per minute at an air pressure of from 50 to 55 lbs. per inch was about 400. The length of stroke varied from 3 to 5 inches. These machines were fixed on a frame, shown in Figs. 6, 7, and 8, one on each of the horizontal arms. The machine on the upper as well as on the lower arm drilled the holes in opposite quarters of the face; when this was done, the arms were turned to the opposite side, and the full number of holes drilled to complete the operation. The time required for boring the holes varied according to the nature of the ground *in the lode*, since it happened that the drilling of the "lode holes" sometimes took double or treble the time required to drill a similar number in the Slate; not through hardness of veinstone, but because of the prevalence of fissures and "heads" diverting the normal path of the tool.

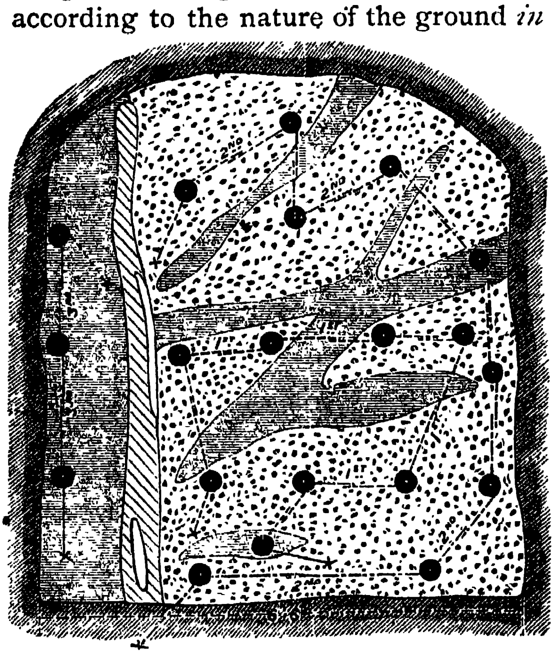

Fig. 142.

Holes.—The sectional dimensions of the level were—width, $6\frac{1}{2}$ feet; height, 7 feet. From the circumstance that it was necessary to carry a portion of the lode with the level, the holes were usually bored, as shown in Fig. 142—(1) To obtain the centre cut; (2) To remove the country rock; (3) To blast down the lode.

The relative position of these holes is shown in Fig. 142. The average diameter of the holes at the bottom was $1\frac{1}{4}$ inch; depth, 44 inches; but holes 52 and 54 inches deep were frequently drilled and blasted.

Charging and Blasting.—The charging and blasting of shot-holes involved three separate operations—the holes 1 were first charged and blasted, then the holes 2, and finally the holes 3. The three several lines, 1, 2, and 3, on the face of the level (Fig. 142) show the circuit wires which connect the electric fuses for each blast.

The following statistics apply to a length of 79 fathoms 5 feet 8 inches driven in the 60-fathom level by six men and three labourers, or nine men in the "pare," during a period of twenty-nine weeks, the nine men tramming the stuff from the forebreast to the shaft:—

Number of machines employed together . . .	2
" holes bored	2194
" feet bored	$8279\frac{1}{2}$
Average depth of holes	44 inches
Number of feet of hole bored to remove a cubic yard of rock	$10\frac{8}{10}$
Number of bits blunted per running fathom . . .	28
Weight of dynamite consumed	1654 lbs.
Average weight of dynamite per hole	$\frac{7}{10}$ "
per lineal fathom	$20\frac{7}{10}$
" " cubic yard	$2\frac{2}{10}$ "
" " ton of stuff broken	0·94 "
Number of cuts made . .	142
Number of tons of stuff removed	1754
Average number of holes per cut	16
Length driven per cut . .	$40\frac{1}{2}$ inches
Average length driven per week	17 ft. 8 in.
Maximum length " "	28 feet

Time occupied in the various operations-

Boring the shot-holes	$1325\frac{1}{4}$	or $41\frac{3}{10}$	of total time.
Charging and blasting	$442\frac{1}{2}$	" $13\frac{9}{10}$	"
Removing the stuff	1055	" $32\frac{9}{10}$	"
Putting in air-pipes and laying railway .	$180\frac{1}{4}$	" $5\frac{6}{10}$	"
Hindrances	203	" $6\frac{3}{10}$	"
	3206	100	

Rate of Driving.—The rate of advance per day of twenty-four hours in tunnel levels is found to vary from 7 to 12 feet, and in mine levels from $1\frac{1}{2}$ to 7 feet. The time occupied in boring the holes must naturally depend upon the number of machines and men employed together, upon the power and handling of the machines, upon the diameter of the holes, as well as upon the nature of the rock.

TABLE II.

DAILY RATE OF DRIVING IN SUNDRY LEVELS BY MEANS OF ROCK-BORING MACHINES.

Name.	Machine	Size of the Level.	Diameter of Hole at Bottom.	Total No. of Men employed.	Rate of Driving per 24 Hours.	No. of Machines employed.	Diameter of Boring Cylinder.	Rock.
			Inch		Feet.		Inches.	
St. Gothard, Airolo	Dubois & François	8·6 × 8·2	$1\frac{1}{4}$	39	10	6	$3\frac{1}{2}$	Mica and schist.
Musconetcong	Ingersoll . .	26·0 × 8·0	$1\frac{1}{2}$	48	10	6	5	Syenite.
Sutro	....	..	$1\frac{1}{2}$	..	..	4	4	....
Maesteg	Beaumont	8·0 × 8·0	$1\frac{1}{2}$	78	8–9	4	4	Pennant.
Anzin	Anzin .	..	..	..	..	4	..	Sandstone.
Halkyn	Beaumont	8·0 × 8·0	..	..	8–9	4	4	Limestone and quartz.
Ballacorkish	Darlington	7·0 × 6·6	$1\frac{1}{8}$	9	3–4	1 & 2	$2\frac{5}{8}$	Tough Slate and quartz.
Blanzy	Ditto	7·6 × 7·6	$1\frac{1}{4}$	9	$4\frac{1}{2}$	2	$3\frac{1}{2}$	Sandstone.
Foxdale	Ditto	7·6 × 5·6	$1\frac{3}{16}$	6	$1\frac{1}{2}$–2	1	$2\frac{5}{8}$	Quartz and spathose iron.
Ditto	Barrow	7·6 × 6·0	$1\frac{1}{4}$	9	$1\frac{1}{2}$–2	1	3	Hard bastard Granite.
Marihaye	Dubois & François	6·0 × 6·0	$1\frac{1}{4}$	9	6–$6\frac{1}{2}$	4	$3\frac{1}{2}$	Shale and grit.
Portskewet	Geach .	8·0 × 8·0	1	66	7–8	2	$3\frac{1}{2}$	Pennant Sandstone.
Cwmbran	McKean	10·0 × 7·0	$1\frac{1}{2}$	29	7–9	2	4	Ditto do.
Minera .	Darlington	6·6 × 7·0	$1\frac{1}{2}$	9	$2\frac{1}{2}$–3	1 & 2	$2\frac{5}{8}$	Limestone, quartz, &c.
Carn Brea Level	Beaumont	8·6 × 8·6	$1\frac{1}{8}$	10 & 2 boys	4	4	4	Hard silicious tin lode.
Ditto Shaft	Ditto	15·0 × 8·6	$1\frac{1}{8}$	12 & 2 boys	$\frac{1}{2}$	2	4	Ditto ditto.
Dolcoath Level	Barrow	8·0 × 6·0	$1\frac{1}{8}$	9	$\frac{1}{2}$	1 & 2	3 & 4	Ditto ditto.

An uniform, clean-cutting, coarse, hard-grained rock may be bored quickly; a fine-grained, tough rock will be drilled slowly; while a fissured, vughy rock will frequently "fitcher" the tool, unless the machines have in themselves an excess of power, and the bit be of a suitable form to maintain the line of the hole.

The weight of dynamite per cubic yard of rock broken will be found to vary from $1\frac{3}{4}$ to $4\frac{4}{10}$ lbs. The number of lineal feet of shot-hole for the same measure of rock is from 4 to 16 feet. When the number of lineal feet of shot-hole is great in proportion to the sectional area of the face, the quantity of dynamite appears sensibly to decrease.

TABLE III.

STATEMENT OF APPROXIMATE WEIGHT OF DYNAMITE USED FOR THE EXTRACTION OF A CUBIC YARD OF ROCK, AND AGGREGATE DEPTH OF HOLE BORED.

Name.	Machine employed.	Diamet 'Sho hole a' tom.	Dep hole.	Weight of Dynamite per Cubic Yard of Rock.	Average Length of Shot-hole per Cubic Yard of Rock.	Rock.
		Ins.	Inches.			
Maesteg	Beaumont		42–48	$2\frac{1}{4}$	$7\frac{1}{2}$	Pennant.
Musconetcong	Ingersoll		120–130	$4\frac{4}{10}$	6	Syenite.
Portskewet	Geach		18–24	$3\frac{1}{2}$	6–7	Pennant.
Cwmbran	McKean		30–36	3	$4-4\frac{1}{2}$	Ditto.
Perka Pits	Dubois & François		..	$2\frac{1}{2}$	...	Quartz and schist.
Carn Brea Level	Beaumont		42	$2\frac{1}{4}$	7	Hard silicious tin lode.
Ditto Shaft	Ditto		48	$2\frac{3}{10}$	$5\frac{7}{10}$	Ditto
Roskear	Ditto		48	$1\frac{3}{4}$	8	Killas.
Dolcoath	Barrow		30	$4\frac{2}{10}$	$11\frac{1}{4}$	Hard silicious tin lode.
Ballacorkish	Darlington		42–54	$2\frac{2}{10}$	11–12	Hard tough Clay-Slate
Foxdale	Ditto		36	$3\frac{1}{4}$	16	Quartz, spar, & spathose iron.
Ditto	Barrow		39	3	$16\frac{3}{4}$	Hard bastard Granite.
Minera	Darlington		30	$2\frac{3}{4}$	15	Limestone, quartz, &c.
Ballacorkish Shaft	Ditto		50–60	$2\frac{8}{10}$	16	Clay-Slate veined with quartz.
Laxey	Ingersoll		30			

TABLE IV.

COST OF BORING BY MACHINERY.

Name.	No. of Machines.	Cost per Running Fathom. Machinery.			Cost per Running Fathom. Hand.			Authority.
		£	s.	d.	£	s.	d.	
Cockerill Works	4	3	0	0	3	12	0	Dubois and François.
Noeux	4	6	0	0	7	6	0	Ditto.
Gosson Lagasse	4	1	15	0	2	6	0	Ditto.
Chartreuse and Violette	4	1	16	0	3	0	0	Ditto.
Ballacorkish	1 & 2	7	0	0*	11	10	0	Barkell.
Foxdale	1	7	0	0*	12	0	0	Ditto.
Ditto	1	10	0	0	17	0	0	Ditto.
Laxey	1	7	10	0*	11	0	0	Ditto.
Minera	1 & 2	9	10	0*	15	0	0	Ball.
Dolcoath	..	17	0	0	25	0	0	Provis.
Carn Brea Level	4	32	0	0	27	0	0	Ditto.
Ditto Shaft	2	50	0	0	90	0	0	Ditto.
West Tolgus	..	83	10	0†	100	0	0	Ditto.

The cost of driving and sinking by hand labour, and with boring machinery, can only be approximately stated. The heading "hand price,"

* Exclusive of cost of compressing air. † Including estimated cost of compressing air.

in the table, is in most instances the estimated price of the ground. The cost of compressing the air is also in some cases associated with other costs which cannot well be separated.

In each of the examples, but one, there is a difference in favour of machinery sufficient, it may be assumed, to include the redemption of the boring-machines, as well as the cost of maintaining the plant.

The relative proportion between the rate of driving by hand, and with machinery in different varieties of rock, as well as the comparative cost of the work, exclusive of cost of compressing air, is approximately as follows:—

Rate of Advance.	Schist.	Ordinary Sandstone.	Hard Grit	Hard Grit and Quartzite.
By hand	20	10	5	3
By machinery	30	25	18	12
Taking the hand price as a unit of comparison, the cost of the work by machinery, exclusive of cost of compressing air	0·9	88	0·65	0·50

It will be seen from the above statement that rock-boring machines afford the best results when boring holes in hard ground. In Schist, the rate of driving is only reckoned one-half more than that obtainable by hand labour, and the cost one-tenth less, whereas in hard grit and quartzite the rate of driving is threefold greater, and the cost one-half less.

TABLE V.

SUNDRY PARTICULARS CONNECTED WITH DIFFERENT WORKS WHICH HAVE BEEN EXECUTED BY MEANS OF ROCK-BORING MACHINERY.

Name.	of m	Sho iche	Len Fee	verage Number of Sl holes made in Face one Cut or Sink.	Number of Boring Machines employe	Number of Square Fee Face to one Boring Machine.	Name of Machines employed.
Mont Cenis		30-48	83	55-65	10		Sommeiller.
Mustconetcong		108-110	216	36	2	55	Ingersoll.
St. Gothard		42-84		26			Ferroux, Dubois. François, McKean.
Portskewet		24-30	64	12-18	2	32	Geach.
Altenberg		20-36	52½	10-12	2	26½	Sachs.
Perseberg		24	72		1	72	Bergström.
Salzbach		21-24	175½	10	1	175½	
Anzin		60-72	57	19	4	14¼	Dubois & François.
Marie Colliery		72	34	30	4	8½	Ditto.
Pierre Dennis		72	52½	..	4	13	Ditto.
Stahlberg		34-30	40	8	1	40	Sachs.
Gonley Colliery		30-40	64	..	1	64	Ditto.
Drybrook		40-50	40	34	1	40	Darlington.
Sir Francis Level		48-60	35	30	1	35	McKean
Minera Shaft		30-36	56	36	2	28½	Darlington.
Minera Level		32-36	46	24-26	1-2	22-23	Ditto.
Johann Colliery		58	228	..	6	38	Sachs.
Ballacorkish Shaft		40-60	86	22-24	2	43	Darlington.
Ballacorkish Level		40-50	45½	17-18	1-2	22½	Ditto.
Carn Brea		42	49	16-20	4	12¼	Beaumont.
South Crofty		..	..	..	1	..	
Cwmbran		30-36	70	10	2	35	McKean.
Dolcoath		..	45	20	1	45	The Barrow.
Maesteg		48-66	64	16-18	4	16	Beaumont.
Foxdale			42	24	1	42	Darlington & Barrow.
Laxey			31½	16-20	1	31½	Ingersoll.
Blanzy			50	16-18	2-3	25	Darlington.

In reference to the question as to the comparative advantages obtainable from the employment of power drills over that of hand labour, some general facts present themselves of the greatest importance to the miner.

1. Any given work may in most cases be executed at a direct cost not exceeding that of ordinary hand labour, and frequently at a less cost, provided the ground be unusually hard for the boring tool.

2. The rate of progress which may be accomplished by means of machinery can be reckoned from three to four times greater than that obtainable by hand labour. In other words, as much exploratory work may be done in one year as is practicable in three without the use of machinery.

3. Levels may be driven a considerable distance without the necessity of sinking shafts or winzes for ventilating purposes.

4. Miners working in connection with pneumatic boring-machines are continually supplied with an abundance of fresh air.

5. The speed attainable through the efficient use of boring-machines will materially tend to quicken the chances of successful results for the capitalists, and to lessen the amount of the capital expenditure which otherwise would be required. Instead of the dead charges incident to an undertaking extending over a period of nine or ten years, they need not continue longer than three or four; that is, to accomplish an equal amount of work.

Levels and shafts free from water will always be driven and sunk more quickly than levels and shafts charged with water; but a great deal may be done to quicken the rate of speed in a sump-shaft by eliminating as far as possible the causes which will conduce to hindrances before commencing the work, and getting rid of delays as soon as they may occur.

The number of machines and hands which it may be desirable to employ in sinking a shaft or driving a level are matters which must be met by the necessities of each particular case. Probably two machines and nine men in a level will be generally sufficient. But three or four machines may run together. Unless, however, the hands are well trained to their work, and adequate provision is made for lessening the time of the charging, blasting, and waggoning operations, the speed and money result will not be in proportion to that attainable by the smaller number of machines.

Fig. 143 illustrates a small plant of rock-boring machinery. On the left hand the compressor is shown communicating with a receiver set towards the right-hand side of the building. This receiver is fitted with a safety-valve to discharge any air which may come from the compressor in excess of the required pressure. From the receiver a main of pipes passes down the shaft, and from this main three smaller mains branch off at right angles into as many levels. In the first level a boring-machine is supposed to be applied to underhand stoping, in the second and third levels to perforating the forebreast with shot-holes which are to be subsequently charged and blasted.

The economic result consequent on the employment of rock-boring machinery will depend mainly upon the proper and effective organization of the work.

The boring-machine must necessarily be a reliable and good one, constructed so as to withstand the heavy wear and tear to which it may be subjected. It must also be of sufficient power to drill the holes moderately quickly. It is, however, of almost equal importance that the apparatus on

which the machines are mounted should be of ample strength for holding them firmly to their work when under the influence of a rapid succession of

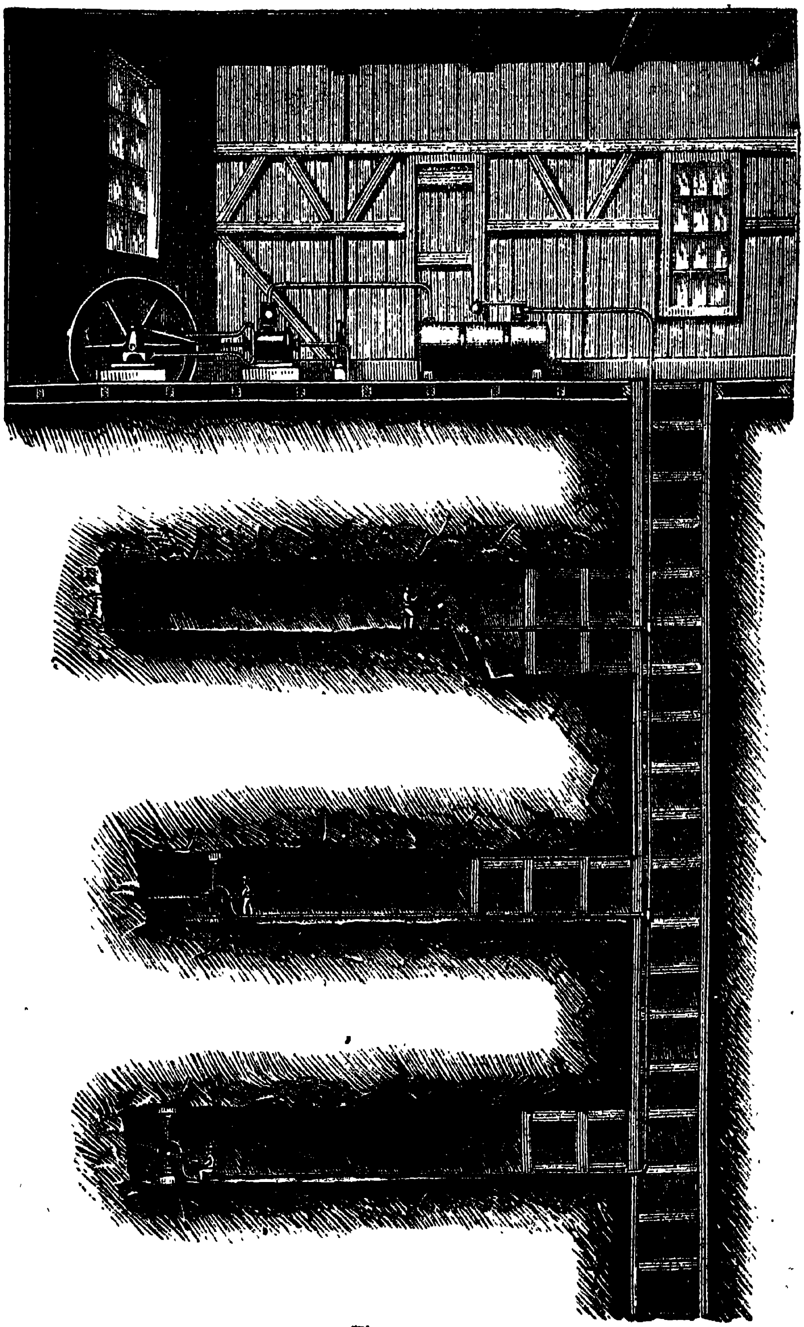

Fig. 143.

blows, while it should be so contrived as to afford every facility for drilling shot-holes in any required position.

For permanent use very high-speed compressors are not desirable, but compressors arranged to withstand all the reasonable wear that can be imposed upon them, and at the same time constructed so as to afford a maximum result for the power expended to produce it.

For the purpose of removing the centre cut the strongest explosive should be employed, and particular care taken to *detonate*, *not* to *burn*, the explosive.

Taking the average bottom diameter of most of the shot-holes bored by the various machines to be 1 inch, it would be important to ascertain if, by increasing their diameter, a lesser number would not suffice for removing the entire cut or sink.

In such case the fewer holes, drilled with machines of increased power, might be valued with the greater cost of the explosive which would probably be required; and in this way the relative advantages of varying the number and diameter of holes could be usefully determined.

Shot-holes should be bored as deep as they may be found capable of effecting the removal of the ground, having also regard to the time of boring the holes, which usually increases with increase of depth.

Electric blasting offers in itself an element of security and success. It would be well, therefore, to ascertain what increase in the normal rate of speed would result, and what percentage of explosive material might be economised, by the use of electric over safety-fuse.

It is scarcely open to doubt that the time is near at hand when boring-machines will form a part of every mining plant; that is, in mines where a considerable amount of work is intended to be done in moderately hard ground. In all cases the drilling-machines and plant should be under the control of a mechanical engineer, rendered responsible for the efficient performance of the apparatus and the economical conduct of the work.

CHRONOLOGICAL TABLE

OF SOME OF THE MOST IMPORTANT EVENTS CONCERNING EXPLOSIVES, BORING SHOT-HOLES, AND BLASTING GROUND.

Partly compiled by Rziha and Drinker, and supplemented with additional information.

A.D.

1280. Albert Magnus, the German friar, describes an explosive powder.
1284. Roger Bacon notices the composition of an explosive powder.
1324. Berthold Schwarz is said to have invented gunpowder.
1412. Gunpowder manufactured in England.
1613. Martin Weigel, mining superintendent of Freyberg, proposed drilling and blasting in mines.
1670. German miners introduced blasting into England.
1685. Tamping with clay known in Saxony.
1687. Lumbe introduced into the Harz tamping with clay, and straws filled with powder for firing the shot-holes.
1688. Singer, of Clausthal, employed small firing-tubes of hard wood.
1689. Thomas Epsly, senr., of Chilchampton, Bath, introduced blasting of rocks in Cornwall.
" Lult, of Clausthal, used pasteboard cartridges.
1717. Fritsch proposed to save powder, and to break the rock by wedges driven into the bore-holes.
1725. At this date the effect of simultaneous firing of several shots was known.
1749. Hungarian miners first introduced the chisel-bit drill into the Harz. For a period of one hundred and thirty-six years from Weigel's day to this date 1749, all drilling had been done by means of crown and cone "bits."
1759. Drilling with a chisel-bit introduced into Saxony.
1760. Thunberg introduced into Sweden tamping with wedges.
1791. Le Plat used sand as a tamping.
1795. Humboldt proposed making the shot-holes wider at the bottom (of a conical shape).

1811. Spangenberg, of Sahl, used wooden tamping-rods, also wooden needles and soft clay for tamping.
1813. Trevithick invented a rotating boring-machine, which was made at Hayle Foundry, Cornwall, and put into operation at some Limestone quarries near Plymouth.
1823. Harris fired a blast by the electric spark.
1829. Needles made of a composition of lead and tin used in the district of Ehrenfridersdorf.
„ Moses Shaw, of New York, fired several charges of powder simultaneously by passing an electric spark through a priming composed of the fulminate of silver.
1831. Bickford, of Camborne, invented the safety-fuse.
1834. Pischel proposed ignition of blasting powder by means of percussion.
1838. Prideaux used oxyhydrogen gas for deepening bore-holes, and with it burnt a hole at the rate of one-eighth of an inch per minute.
1839. Hague injected water into air-compressing cylinders.
1840. Borer holes made with rotary drills at Lankowitz.
„ Cast-steel borers used in the Derbyshire mines.
1844. Brunton, of Cornwall, proposed using compressed air for working drill hammers, the air after use to improve ventilation.
1845. Cast-steel drills tested at Freyberg.
1846. Schonbein exhibited a sample of gun-cotton at the British Association.
1847. Sobrero discovered nitro-glycerine.
1849. Randolph, of Glasgow, introduced into an air compressor a spray of water for cooling the air during its compression.
„ Couch, of Philadelphia, patented a "lance" percussion drill.
1850. Robert Hunt, F.R.S., made low-tension electric fuses, which were used in sinking a pit at the Abercarn Colliery, South Wales, the firing of the fuses being effected by means of an electric battery.
1851. Fowle, of Philadelphia, patented a direct-action percussion drill.
„ Cavé, of Paris, invented a reciprocating percussion drill.
1853. Piatti proposed using compressed air in the construction of the Mont Cenis Tunnel.
1854. Bartlett's rock drill tried at the Mont Cenis Tunnel.
„ Experiments with compressed air made at the Mont Cenis Tunnel.
„ Schumann invented his percussion power-drill.
1857. Schumann's drill employed in the Freyberg mines.
„ Sommeiller invented a drill for use in the Mont Cenis Tunnel.
„ Ebner employed a frictional-machine for blasting.
„ Schwarzkopf's drill tried at Bingen.
1861. On the 1st of January, Sommeiller's perfected drill commenced to work at the Mont Cenis Tunnel.
„ Lisbet applied his machine in boring soft rock, coal, soft Limestone, &c.
1862. Bornhardt's air-tight electric firing-machine brought into successful use.
1863. Edward Crease introduced his rock-boring machine into the Clogau mines, North Wales.
„ Ditto, invented the double-headed flying piston.
„ Lows's rock drill invented.
„ Sachs's rock drill invented.
„ Nobel applied nitro-glycerine as a blasting agent.
1864. In March, Carl Sachs's machine introduced into the Altenberg mines, Aix-la-Chapelle.
1865. Gun-cotton tried at Hoosac Tunnel.
1866. Lithofracteur manufactured by Engels, near Cologne.
„ Nitro-glycerine tried with great success in the Hoosac Tunnel.
„ Jordan and Darlington invented the rifle-bar and ratchet-wheel for turning the piston carrying the drill.
„ The Burleigh drill successfully introduced at the Hoosac Tunnel.
1867. Jordan and Darlington invented the straight and spiral shot, and double ratchet-wheel, for turning the drill.
„ Dynamite patented in England.
„ Döring introduced his boring-machine into the Tincroft mines.
„ Dubois and François's rock drill invented.
1870. Beaumont and Appleby's diamond boring machinery introduced at the Croesor United Slate quarries, North Wales.
„ Sir George Denys, Bart., commenced driving an adit for the Old Gang Company, Yorkshire, by means of the McKean drills.
1873. The Ferroux rock drill invented.
„ The Darlington rock drill invented.
1874. The Mowbray mica powder patented.
„ Electric blasting introduced by Darlington into the Minera mines, Bornhardt's machine, the blasting-stick, and wire electric fuses being employed for that purpose.
„ Darlington invented a spinning-piston machine.
1876. The Beaumont rock drill employed at Carn Brea.
„ Darlington introduced the vertical shaft sinking stand at Minera, and arranged an 8-inch diameter sinking pump at Ballacorkish, in the Isle of Man, for carrying the boring-machines.

The rock-boring machines in use are, in many of their details, alike. The cylinders are mounted in cradles, and are advanced and withdrawn by a long screw, while the pistons are generally reciprocated by means of a

tappet or "flying valve." The peculiarities of the Ingersoll drill consists in effecting the movement of an ordinary slide valve by means of tappets entering into and set at each end of the cylinder. In the Barrow machine the valve is shifted and the movement of the piston reversed by a tappet set between a double-headed piston engaging in a plate valve. The Burleigh and Cranston machines are types of each other. The valve in each is shifted by a tappet set at the rear end of the piston-rod. In the McKean drill the valve is semi-rotated by a tappet set on a back piston rod, while the turning of the piston and tool is effected by spiral gear at the end and outside of the cylinder. The Schram, Eclipse, Cornish, and Beaumont machines are fitted with what may be designated piston-flying valves, to which the pressure fluid is distributed by the main piston. In each and all of the machines in use, the compressed air is admitted to the lower side of the piston before the blow is struck so as to reverse the action of the machine.

Leschot, Taverdon, Pittar, and Beaumont have each contrived diamond drills and applied them to the boring of shot-holes. Hand boring-machines have been devised by Jordan and Macdermott. The former employs a cylinder in which the piston is lifted by a "snail cam." Two points are accomplished by this movement—the piston and tool are turned, the air is compressed within the cylinder, and when the cam is released from the tappet the blow is smartly struck.

PERCUSSIVE ROCK-BORING MACHINES IN USE, AND CHARACTERISTICS OF SAME.

Typical Machines.

(*a*) Tappet-worked valve .	11 machines	(*e*) Ordinary D valve . . .	1 machine
(*b*) Flying valve	7 "	(*f*) Tappet and semi-rotary valve	
(*c*) Valveless	4 "	(*g*) Valve independent of machine	
(*d*) Tappet and Flying valve	2 "		

Name of Machine.	Inventor of Typical Rotating Device.	Advance of Machine.
(*a*)		
Burleigh	Burleigh	Automatic and Hand
Dunn	*Wheel and Rifled Bar*	
Cranston	Hand	Hand
Roanhead		
Barrow	Hand	
Geach	Burleigh	
Brydon and Davidson	*Wheel and Rifled Bar*	
Ingersoll	"	Automatic and Hand
Grunez	Burleigh	Hand
Rand and Waring	*Wheel and Rifled Bar*	"
Meyer		Automatic
b		
Beaumont	*Wheel and Rifled Bar*	Automatic
Schram		Hand
Edwards		
Darlington	*Wheel and Rifled Bar*	Hand
Frohlich		Automatic
Eclipse		
Cornish Rock Drill		

Name of Machine.	Inventor of Typical Rotating Device.	Advance of Machine.
(*c*)		
Darlington	*Wheel and Rifled Bar**	Hand
	Darlington	Automatic and Hand
Levet	Levet	
Excelsior	*Wheel and Rifled Bar**	
(*d*)		
Dubois & François	Dubois and François *	Hand
Ditto (Anzin)	Burleigh	
(*e*)		
Sachs	Sachs	Automatic
(*f*)		
McKean	McKean	Automatic
Ullathorne (Champion)	*Wheel and Rifled Bar*	Hand
(*g*)		
Ferroux	Ferroux	Automatic

* Wheel and Rifled Bar in Italics invented by Jordan and Darlington, 1866.

EXPLORATION.—Everything necessary having been done to warrant further subterranean working, so as to extract the ores from the mineral veins or beds, with the least waste and the utmost economy; the manner in which excavations are to be made depends entirely on the nature of the ground which is to be opened. Werner adopted the following classification, and he selected for each kind of ground a special tool—or a process of working—which he thought the appropriate mode of proceeding:—

a.—Loose or running ground (vegetable earth, sand, and earthy deposits) require *the shovel.*
b.—Soft or fair ground (strongly coherent sands, or clay decomposing masses, disintegrating Granite, friable veinstone) require *the pick.*
c.—Semi-hard ground (some Limestones, Killas, copper, Slate, gypsum, mineralised Granites, rocks generally which are partially decomposing) require *the gad (Saxon).*
d.—Hard ground (Granite, Elvan, Gneiss, Porphyry, Basalt, Hornblende, Serpentine, &c.) require *blasting.*
e.—Very hard or *tight ground* (this would apply to some highly silicious rocks, to some conglomerates, &c. &c.) *by means of fire.*
f.—Soluble rocks (detrital matter and disintegrated masses, massive deposits) *by means of water.*

This classification does not entirely hold good in the present day. The application of fire, for example, is almost obsolete, indeed it is only under the most peculiar cases that it is ever used. The removal of *country* (especially deposits of gravel or soft ground) by water applies only to the process of *hushing* in the north of England, and to hydraulic mining, as it is employed in America and Australia, for the removal of auriferous deposits. When we come to speak of tools, a description of the varieties demanded for particular work will be given.

There will be some advantage in referring to the ordinary modes used by the older miners, notwithstanding the notices already given.

In 1671, a writer, who appears to have been well acquainted with the mines of Cornwall and Devonshire, published in the "Philosophical Transactions"* some details of the mode of working mines, at that time, when mining was in a very primitive state. Levels were then driven at about five fathoms under each other; and the water was raised either to the adit, or to the surface, by means of "a winder and keeble, or leathern bags, pumps, or buckets."

"When we have found our load, the *essay hatch* (*i.e.* a shallow pit as sunk in costeening) exchanges its name for that of a *tin shaft* or *tin hatch*, which we sink down about a fathom, and then leave a little long square place, termed a *shamble*, and so continue sinking from east to west, till we find the load to grow too small, or to degenerate into some kind of weed, as *mundick* or maxy, &c. Then we begin to drive east and west—as the goodness of the load or convenience of the hill invite—which we term a drift, 3 feet over and 7 feet high, but in case the load be not broad enough of itself, then we usually break down the *deads* (unprofitable parts of the lode) first on the north side of the load, and then we begin to rip the load itself. The *beele-men*† rip up the *deads* and ore, the *shovel* men convey it off and land it, by casting it up with shovels from one *shamble* to another, unless we have a *winder* (windlass) with two keebles, which as one comes up the other goes down."

The Cornish are essentially a Celtic race. The mixture of Oriental, of

* "Philosophical Transactions," No. 69, p. 2096. † Bal-men, men working a bal or mine.

Saxon, of Danish, and of Spanish blood can be traced in some districts—more especially on the Cornish coast; but, in the mining districts the superstitions of the Celts still linger, and we find the miner persistently walking in the footsteps of his ancestors. One striking characteristic is the tenacity with which the miner pursues a certain course of action "because his father did so before him." It becomes, therefore, interesting to examine the changes which have taken place during a series of years. The quotation just given, as the mode of working in 1671, describes the exploration of mines, much as it is explained by Carew in the latter part of the sixteenth century, and he was greatly assisted in this by Sir Francis Godolphin, who was regarded in those days as a high-class authority on Mining.

In 1758 Borlase published his "Natural History." We have, therefore, an example of mining, as practised at that time, in the following:—

"The lode being found," Borlase says, "three things are necessary to be considered by the miner: *first*, to dispose of the barren rock and rubble; *secondly*, to discharge the water, which every lode yields more or less, and generally in quantities sufficient to obstruct the labourer if not duly attended to; *thirdly*, to raise the tin [or copper; the copper mines of Cornwall were of small importance in the time of Dr. Borlase]; and all these are easily performed when the workings are near the surface; but the difficulties increase with the depth, and skill and care become still more and more necessary. Indeed all the mechanical powers, the most forcible engines, and the utmost sagacity of the chief miners, is often too little and vain, where the workings are deep and many. Anciently they worked for tin, especially when found disposed on floors, by laying open all the ground, as they do now in stone quarries. Several of these openings, called *coffens*, are still to be seen in the parish of St. Just and elsewhere; but this being a method too operose and extensive, it was not long, we may imagine, before the tinners learned to make passages into the bowels of the Earth, of dimensions no more than necessary, to examine the lodes and bring off the ore, *and this is what is properly called mining*. The arts necessary to mining are many, and every mine almost requires a peculiar management. Mining, therefore, must be learned by practice, by experience, and masters—not from books, the rules of which, though ever so just, must be frequently suspended, altered, qualified, and superseded, according as the various circumstances require."

Sir H. de la Beche* gives a carefully prepared abstract of Borlase's description of Pool mine in Illogan, and describes the mine section engraved in the "Natural History," which description it will be an advantage to quote:—

"To afford a view of the manner in which a mine was worked in his time, Borlase selected the Pool mine, in the parish of Illogan. In that mine there were seven shafts upon the lode, upon one of which there was a fire-engine working the pumps and raising the water of the mine, which it unwatered to the adit level, 20 fathoms from the surface. Another shaft had a whim on it, probably a water-whim from its name; and the others had common winzes at their heads, though two of them must have been 45 fathoms and one 55 fathoms deep. The lode was worked by stoping, or in steps, so that many men could readily be employed at the same time upon it—a practice probably

* "Geological Report on Cornwall, Devon, and West Somerset." By Henry T. de la Beche, F.A.S.

ancient, and derived from working the open lodes by stages, the miners throwing the ore and rubbish from one stage to another until they reached the surface, as has been supposed by Pryce. The walls of the lode were supported by timber, and planks were laid upon them in proper places, on which the *deads*, or unprofitable parts of the workings, were thrown. Captains superintended the work, and saw that it was properly conducted, and it appears that they employed the magnetic compass, or dial, in ascertaining the bearings of work to be executed, such as sinking shafts, &c.

"With respect to the machinery employed to unwater the mine, Borlase enumerates the *water-whim*, the *rag and chain pump*, the *water-wheels and bobs*, and the *fire-engine*, independently of the hand and forcing-pumps for small depths. The whim seems to have been the same with the common horse-whim of the present day, employed to draw ores from moderate depths, the only difference being that water was raised in the kibbles, or buckets, instead of ore. The rag and chain pump consisted of an iron chain, furnished at intervals of two or three feet with knobs of cloth, stiffened with leather, which, being turned round by a wheel two or three feet in diameter, furnished with iron spikes that fitted into the links of the chain, and made to pass through a wooden pump-cylinder about 6 or 8 inches in diameter and 12 or 15 feet long, brought up the water which rose up into the bottom of this wooden cylinder between the knobs of rag. The surface of the water to be pumped out was necessarily some height above the bottom of the cylinder, and beneath it the chain, with its rag-knobs dipped, in its passage round the wheel and through the pump-cylinder. These pumps were worked by hand in the mines, and afforded a stream of water in proportion to the circumvolution of the wheel turned. Rag and chain pumps were then also, it appears, worked by small water-wheels in the tin-stream works near St. Austell. The water-wheels with bobs sometimes worked pumps with brass cylinders, and seem to have been much used, as Borlase complains that from the great want of water in summer, many of these engines could not work from May or June to October—a great hindrance, it is observed, to the mines at that season of the year."

Pryce published his "Mineralogia Cornubiensis" in 1778. He was a better miner than Borlase, and consequently his description is more exact. He supposes "The present methods of working of tin mines by deep shafts, and by driving and stopeing under the firm ground, has been practised more than three hundred years past. Prior to those means for raising of tin, they wrought a vein from the *bryle* to the depth of 8 or 10 fathoms, all open to grass very much like the fosse of an entrenchment. This was performed by mere dint of labour, when men worked for one-third of the wage they now have. By that method they had no use for foreign timber, neither were they acquainted with the use of hemp, or gunpowder." After describing the process of *shammeling*, which has been already sufficiently explained, Pryce says: "This, with streaming, I take to be the plain simple state of mining in general three centuries ago, and from hence is derived the custom of *shammeling* both above and under ground at this time; for in the clearing of attle (deads) or filling the kibble with ore the miners prefer a *shammel*, which is a stage of boards, for the more light and easy use of their shovels. . . . . The method of shammeling, even in those moderate times, has been expen-

sive where a very small lode of tin occurred in a hard country. To remove a dense hard stratum of rocky overburden must be very fatiguing and perplexing; therefore they found it most advisable to sink shafts down upon the lode, to cut it at some depth, and then to drive and stope east and west, upon the course of the lode. . . . . We shall now set forth the first arrangement for working a mine, in order to which the principal thing to be thought of, is a shaft to cut the lode at twenty or thirty fathoms deep, if it is possible to be done. Here it is necessary to form some judgment of the inclination or underlie of the lode, before we attempt to sink a shaft; for instance, if the lode underlies to the north about 3 feet in a fathom, and a shaft is designed to come down upon the lode in 20 fathoms sinking, the miner must go off north, from the back of the lode, full 10 fathoms and there pitch his shaft, by which means he is certain to cut the lode in the shaft, about 20 fathoms deep; because for every fathom the lode descends in a perpendicular line, it is also gone 3 feet to the north of the perpendicular."

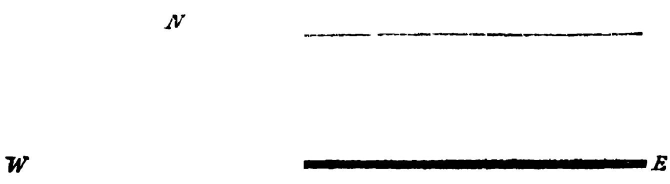

Fig 144.

But to render this more conspicuous, let the line W E, Fig. 144, represent the back, or surface of a lode pointing east and west, and whose underlie is north; by sinking a shaft upon this back, it will soon be deserted by the lode, which is gone farther north 3 feet for every fathom that is sunk upon that line; so that when the lode is 20 fathoms deep it must be gone north to the imaginary line N, where another shaft must be sunk to cut the lode at that depth.

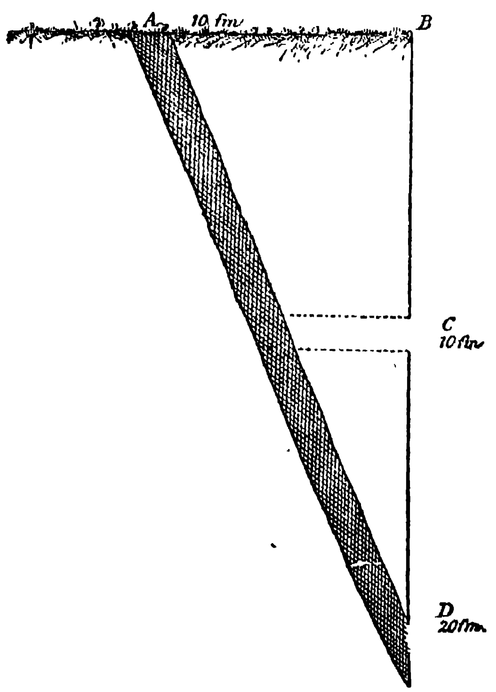

Fig. 145.

"A proper working shaft upon which a whim may be erected, if necessary, should be 6 feet long and 4 wide, where large water-barrels may be wanted; and the harder the ground is, the longer and wider the shaft ought to be, that the men may have the more liberty to work and break it, the area of a large shaft being more easy to rip up where the ground is hardest, than of a small one, where it is more confined together, and breaks in shreds of stone. . . . . A fire-engine shaft ought to be at least 9 feet square, or 10 feet by 8; or, in fact, to contain three shafts in one, which must be partitioned into three compartments all the way down, from grass to the deepest bottom of

the mine. One half is divided for the pumps and engine work; three feet of the other is proportioned for a footway to go down and rectify the pumps when amiss; and the remainder is divided also by a partition of boards for a whim-shaft to draw the deads and ore from the *sump* of the mine."

Pryce gives the number of men required; but as this must be regulated by the conditions of the mine, and determined by the experience of the agent or engineer, it is useless to quote his remarks. He proceeds:—

"The working shaft being sunk downright until it cuts the lode, they open the vein or sink the body of the shaft through it; and if they think the vein is worth following, they sink the same shaft deeper in the body of the lode, upon its inclination or underlie, whence the shaft becomes, and bears the name of an *underlier*; at the same time they *turn house*, as they call it, from the bottom of their perpendicular, or from the top or beginning of the *underlie*. So that, when the lode is well impregnated, they *turn house* by driving or working horizontally on the course of the vein, either to the east or to the west, or both, as they find it most likely to answer their expectations, in order to make a fuller trial and discovery. Where the lode answers well, in thus driving upon it, they continue to do so, till they are prevented by want of air, or till the end of their workings is too far from the shaft, and the expense of rolling back the stuff to the shaft is great and incommodious; then it is proper to put down another shaft. . . . . Meanwhile they are mindful to sink their first shaft, in order that they may work away the lode from thence in stopes, and have a little *sump* or pit in that place, as a bason for receiving the water of the lode . . . . *Adit.*—If the lode lies in ascending ground, they quit the vein for the present, and go down to the most convenient place in the valley, and from thence they bring in a trench, drain, or conduit, which they call an *adit*, *tye*, or *level*, and so they work, and drive this passage through the hill in a right line to the lode, with very little loss of the level they began from."

The conditions remain at the present day much the same as those which prevailed when Pryce wrote, and his remarks are applicable to our modern mines. If the run of the veins is from east to west, or nearly so, the shortest and cheapest adit will be one driven from north or south, unless very hard igneous rocks intervene. If this should occur it will be advisable to seek for a cross course or cross gossan. If the gossan does not exceed 3 feet in width it is considered favourable, because the adit may be driven without the use of timber to support the sides.

Where the rock through which the adit is to be driven is much fractured, or is in a loose, decomposed state, it will be necessary to support the sides and the roof with timber. Sometimes it is considered advantageous to construct an arch from the stones broken out of the workings. As a proof of the small advances which have been made in the construction of levels, it may be stated that in many parts of the country very ancient adits have been discovered, constructed with stones which have been carefully cut and squared.

The adit, as it is to be used for draining all those portions of the mine which are above the level found to be convenient for the discharge of the water, is usually about 6 feet high and a yard wide. Under special con-

ditions the height and breadth are increased. The depth at which the adit is driven depends upon the lowest level obtainable in a valley, or on the sea-shore.

If a mine has been started by sinking a shaft in a hill, for the purpose of removing the water which may accumulate in such a shaft, and thus impede the work of sinking, it is the most economical process to drive a level from the base of the hill so that the water draining from above may flow out. Of course this drain is only available for such gathering of waters from above. When, by sinking the shaft, the accumulation is below the adit, the water is drawn up to it by some mechanical means; thus the labour is saved of lifting the water through the space which is between the adit and the mouth of the shaft on the hill.

In driving an adit it becomes necessary, after the hill has been pierced to a certain distance, to adopt some arrangement by which the miners may be supplied with fresh and pure air. By the processes of respiration, and of combustion from the burning of candles, the air is soon contaminated with carbonic acid.

One plan of effecting the ventilation of the end of an adit is to lay boards, H, on the bottom of the adit from its mouth, A, Fig. 146, to its end E, so that a hollow space is left below them, and to stop the spaces between them with clay. This arrangement is called a *soller*, and it forms a channel through which the air flows and reaches the men at H, when it returns and flows up the shaft D. A series of iron pipes, or even pipes of canvas, may be used as temporary expedients for obtaining the same end. To make the matter clearer with regard to driving and sollaring an adit, let us suppose A to be the *tail* of an adit, all open to grass till it enters the hill, a little farther on they put down an adit-shaft at B for air or for the removal of *deads* from the mine. The next shaft, C, is sunk for the same purpose, and so is D, which may be regarded as the working shaft, the refuse being drawn up through this shaft by a windlass fixed at the surface. The apparatus above the shaft C is for the purposes of ventilation. The wind trumpet-mouth, *a*, is kept opposite the wind, which, blowing into it, passes down the pipe G into the adit. If this does not prove sufficient, a *soller* is placed as described along the bottom, which discharges the air up the shaft, there being a door at K. Sir Robert Moray* describes a method practised at Liège for driving adits without air-shafts. This is done by erecting a chimney 30 feet high, and a furnace at the tail of the adit, from whence an air-pipe is continued through the

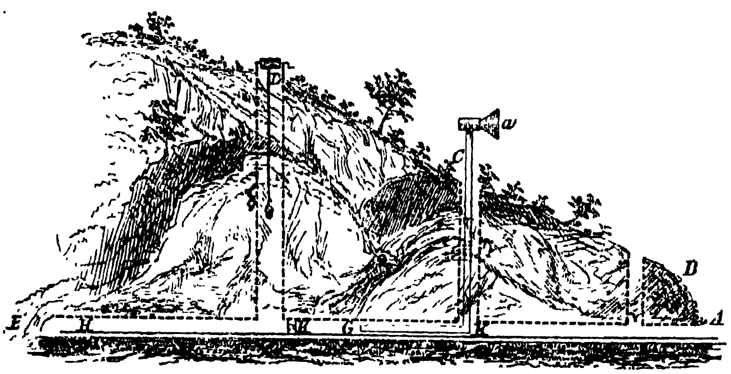

Fig. 146.

* "Philosophical Transactions," No. 5.

adit, whereby all foul air is drawn by the fire into the chimney, so that a current is generated, and this removes all the impure air from the adit. This mode of ventilation is frequently used in our collieries, but it is rarely adopted in our metal mines.

Adits are not generally of any considerable length, beyond the extent of the sett; but sometimes, when several mines have been embraced within the drainage system, they have been driven for many miles. If the adit passes through hard ground, all the conditions will be of the same general character as those for driving levels underground and for the ordinary processes of mining.

Shafts.—Access to a mine is always by means of a shaft (called in France *puits* or *bure*; in German, *schacht*). The question as to the best position for a shaft is a very important one, and this can only be determined by bringing all the advantages of experience to bear on the question. It is usual to sink what may be regarded as the principal shaft, as near as can be determined to the probable centre of the sett and the middle of the workings. This shaft is commonly called by the miners the *sump-shaft*, because the largest quantity of the water is drawn through it, or the *engine-shaft*, as the engine will be fixed in it. The most satisfactory position for a shaft will be regulated by several considerations, depending in a great degree on the character of the surface and the nature of the rock to be pierced.

This being settled, the next question to be determined is, whether the shaft shall be vertical or inclined. A vertical shaft is for almost all practical purposes the most convenient; but, it is sometimes thought to be advantageous to cut it upon the underlie of the lode. The advantages of the truly vertical shaft are considerable, especially where the shaft is to be used for pumping machinery. Considerable inconvenience constantly attends any deviation from the vertical to an inclined direction; as a general rule, too, a vertical shaft is the more economical for winding. It is thought by many miners that sinking the shaft on the underlie of the lode has its advantages in the facility afforded for the removal of the ore. These are, however, questions which can only be solved on the mine, after the peculiar character of the strata through which the shaft will pass has been ascertained, and the dip of the lode determined.

Shafts are of several kinds. The deepest shaft, and most important, is that one which is to be used for pumping water from the mine. The shaft for winding, which is frequently not so deep, is often convenient to use for pumping, either by a separate engine or by rods from the pump-shaft; it is then termed a flat-rod shaft.

If a lode inclines much from the perpendicular, it is sometimes considered the best course to sink *on* the lode rather than *in* the dead ground; such shafts are termed oblique, inclined, or underlay shafts, while those that are perpendicular are termed "right shafts."

In Cornwall, where the lodes are of moderate breadth, and the "country" (*i.e.* the enclosing rock) of ordinary hardness, by opening the lode to a certain length, you have a shaft corresponding to the size of the lode, and generally the ore thus obtained will meet the expenses of sinking. This is often important, as at the same time as the process of sinking is going on, the lode

itself is being explored. It is still a question amongst many practical miners, whether it is more economical to sink a shaft upon the lode, or to cut a perpendicular shaft, and drive out cross cuts at intervals, to explore it. The general feeling is in favour of vertical shafts. If the sinking is begun on the back of a lode, it is inconvenient when the lode alters its underlay. This occasionally takes place suddenly, and there is then difficulty and expense, in adjusting the cranks of the machinery—so much so, that it is often advisable to cut away the angle on the foot-wall side. There are many cases in which it would be difficult to deal with the lode otherwise than by these inclined shafts. It will, however, always be important to consider when inclined shafts have fulfilled their purpose, and to study the propriety of cutting a perpendicular one. If we look at most of the very deep mines, which are of course the oldest mines, it will be found that they have generally commenced by working on the lode, and having reached a productive piece of ground, the expense is incurred of an entirely new arrangement, and a perpendicular shaft sunk from the surface, to intersect the lode at a considerable depth. At Tresavean mine the principal shaft intersects the lode at a depth of 250 fathoms. Mr. W. W. Smyth gives the following remarkable example of the changes in direction in a shaft: "A rectangular shaft was carried down to the adit level at a depth of 20 fathoms; there it met the lode dipping towards the south, and was sunk on, until at the 14-fathom level below the adit it met a lode dipping the other way; the miners preferred the look of the latter, and sunk on it with much regularity to the 112 fathoms, where they again met with a lode dipping in the opposite direction and followed it." This is, however, not a common case, and it should not have been allowed to exist. In some cases inclined shafts are very convenient, and absolutely necessary where the mine is worked under the sea. The inclined shaft at Botallack is a fine example of this. It gave a convenient mode of ascending and descending, to the men; it furnished an effective mode of ventilation; and was very convenient for loading the waggons, and drawing the ores to the surface.

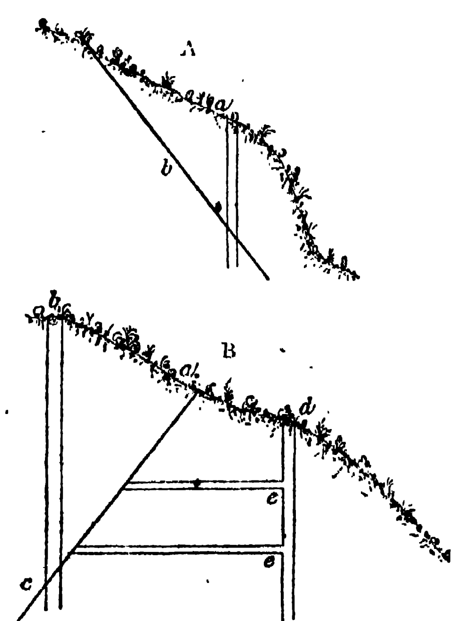

Fig. 147.

If you have a lode on the side of a hill, which is likely to be productive at a moderate depth, dipping in the same direction as the slope of the hill, the shaft *a*, Fig. 147 (A), will be put down on side of the hanging wall to intersect lode *b* in depth. If the lode *ac* (B) dips contrary to the incline of the hill, the miner may either sink in the lode itself, prove it as he proceeds, or he may sink a perpendicular shaft, *b*, higher up the hill than the outcrop of the lode, intersect the lode in depth at *c*, or put down a shaft, *d*, on the foot-wall side and drive out cross cuts *e e*.

The sizes of shafts vary considerably. In some of the old tin mines in Cornwall, and in a few of the ancient lead mines in the North and in Wales, we find shafts only 3 or 4 feet in height and only 2½ feet in width. In metallic mines at the present day the dimensions are 6 feet by 5 feet, or 8 feet by 6 feet; and engine-shafts for pumping and for the ladders for men, 11 feet, 12 feet, and even 13 feet by 8 feet are the usual widths. On the Continent they construct shafts much larger than this, and even in this country, in the collieries, they are often of a more extensive diameter. Subsidiary shafts are generally sunk in a good mine; they are usually placed at intervals of 20, 30, or 40 fathoms, and are termed *winzes*. These are useful as subdividing the ground for the convenience of working, and for purposes of ventilation.

According to the nature of the ground through which a shaft has to be sunk, the question of the security of its sides has to be carefully considered. It often happens that a shaft sunk in the older rocks is sufficiently secure, the strata through which it passes being firm enough to stand without any support, but as a general rule it is safe to protect the miner from the falling of stones, by shielding the sides with timber. Any shaft which is only to serve a temporary purpose is always timbered. The timbering is composed of planks overlapping at their ends, where they are cut obliquely so as to adapt them to the form of the shaft. This framing has laths or poles placed behind it for the support of the sides, according to the nature of the ground. They are fixed in descending order, and are suspended, by means of a series of straps or bearers, to a carrying frame whose sides are prolonged, so that they rest either on the surface or in recesses cut in the solid rock. This timbering is removed frame by frame, as the nature of the ground will permit, to make room for the permanent lining of masonry as it is built. At the Alport mines, in Derbyshire, where the finished shaft was 12 feet diameter and circular in form, this method was adopted, the walling of the shaft being of the stones of the district very carefully squared.

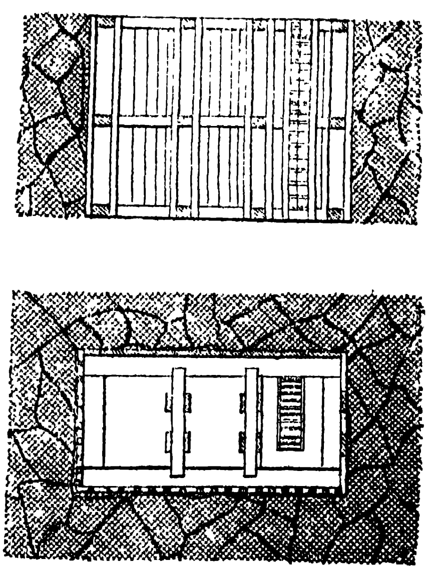

Fig. 148.

When timbering is intended to form a permanent lining, the sections of the shaft are rectangular, and the frames are carefully constructed, so as to have them at invariable distances, and everything is made very substantial, so that repairs may be required as seldom as possible. The size of the lesser side of the rectangle is determined by the size of the *kibbles*, skips, or cages that are to be used, while that of the greater side is regulated by the compartments which may be required; for example, it may be advisable to secure a compartment of the shaft for ladders, and another for pumping, or one compartment only may be required. The size of the rectangle having

been determined, the shaft is laid out so that the longer side is parallel to the strike of the lode. A set usually is constructed of four pieces of timber—two wall plates and two end pieces—which may be either round or square. These sets are fixed vertically, and maintained 5 or 6 feet apart by means of *studdles* (supports) placed in the angles (Fig. 148). Where the nature of the ground admits of it, the sets are built, in series, upon each other. Each series begins with a set of bearers, the wall plates being made longer than usual, and their ends are placed in deep recesses made in the solid rock. Poles or laths are placed behind and jammed by means of wedges. When the timbering is constructed from above and carried downwards, the sets are hung from an upper frame by pieces strongly nailed from one set to the other. A shaft in loose ground may thus be lined with frames close together.

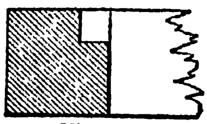
Fig. 149.

The dividings of the compartments help to stay the wall plates. The pieces of which the *dividers* or *buntons* are formed are cut as shown in Fig. 149, so that they may be utilised as stays and serve to support the wall plates. The interior surfaces of the sets and dividers may serve to carry the guides for the cages, or, if an air-tight casing is required for ventilating purposes, the casing of boards may be fixed against the sets.

It is usual in timbering a shaft to have the frames pierced, whether of round or square timber, by taking off half the thickness at the ends. When ground is reached which is considered as being sufficiently secure to put in transverse beams as bearers, sometimes this is done on both sides of the shaft. Frequently a frame of four timbers will be placed on the bearers and at the corners of the joints, studdles, or struts. If the shaft is of extra size, a pair of studdles may be placed in the middle; these struts are generally about 10 feet long; then another frame will be placed on them, and thus timbering of a more permanent character will be secured. Planks will be driven in around the frames, and any spaces which may occur will be filled in with waste wood or stone, so as to prevent the framework falling out of position.

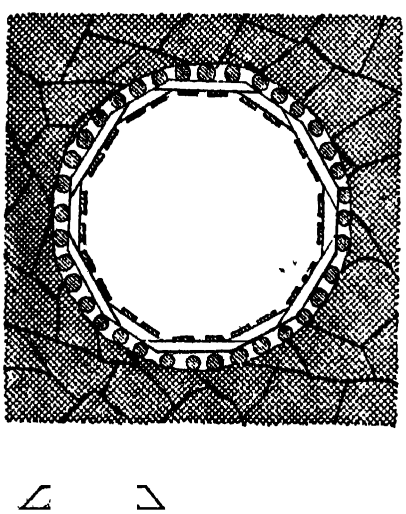
Fig. 150.

The construction of a shaft is of so much importance that every care should be taken to ensure the most perfect method. Walling should always be preferred to timber; and although as a temporary arrangement timbering may be employed, yet it is always advisable to secure a curvilinear form, so as to be suitable at any time for the employment of masonry.

The excavation should have a polygonal form, circumscribed about a circle, and its diameter should be equal to that intended for the shaft in a finished state, and allowance must be made for the walling whenever it may be required by adding to the shaft in width twice the thickness of the walling. It is proper to cut the pieces of timber obliquely, so as to adapt them to the polygonal

form, when the pieces are fitted to overlap each other. The poles supporting the sides are put in place in descending order, and are suspended by a series of *bearers* to a carrying frame, the sides of which are prolonged so that they rest either on the surface or in recesses formed on the solid rock. This timbering is removed when masonry is to be built up, frame by frame, so as to make room for the definite lining of masonry which is intended as a permanent construction.

Mr. W. W. Smyth, in his "Lectures on Mining," gives the following instructive description of timbering:—

"Some of the most remarkable timbering of late years is that introduced in the Comstock district, where the shafts in some instances have been attempted to be carried through the body of the lode, and maintained there in the midst of a mass of loose material, and where no expense has been spared, in some cases, to introduce timber of great size and strength, rendered necessary by the great dimensions of the shafts. The plan of one of these shafts is very instructive in this point of view.

"Take a shaft of 24 feet long, fitted with timber 8 to 14 inches square, having 3-inch planks driven behind the frames all round the sides, forming what we call 'lagging.' The length of the shaft is divided up into convenient compartments by means of props, which are of very great importance in preventing the sides from collapsing under the great lateral pressure. These props are generally placed in steps, two props to each principal frame. They are very important also for the attachment of the guides for drawing. This has generally been carried out with round timber; in some mines 14-inch square timber has been used. In certain mines this timbering has collapsed, and it has been necessary, after a very short time, to take it out and replace the sets in close proximity to one another."

When the miner has to deal with loose ground, so that the sides of the shaft must be supported at once, the principle adopted should be to place the sets as the shaft is deepened. Each set is hung from the one preceding it, and the laths, whether jointed or otherwise, are driven in behind. The laths are often driven in advance of the sinking, and the bottom of the shaft is covered with planks, so as to allow the excavation of small portions at a time. The securest plan is to begin an excavation in the centre of the pit, which should be lined with boards nailed to a square frame. This serves a double purpose; it divides the sinking and forms a well to receive the water, from which it can be pumped or otherwise removed without taking up the sand. The accompanying woodcut, Fig. 151, represents, in plan and section parallel to the wall plates, this arrangement, and Fig. 152 gives another section parallel to the end pieces, showing the vertical pieces which are placed in the corners and stayed against each other.

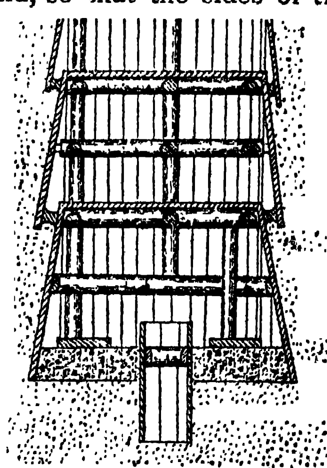

Fig. 151.

There are several questions to be considered relative to the timbering of

shafts. In the first place is the prime cost of the timber, varying much in different localities; and then the maintenance of the timbers, which is greatly affected by the condition of the atmosphere of the shaft. In some mines, and in certain parts of mines, timber is rapidly affected with dry rot, especially where the heat is considerable and the atmosphere heavy. This rot cannot always be detected on the surface of the wood; where it is suspected, it is necessary to scrape off some portion and test by the hammer—if a dull heavy sound is given at each blow. Experience has shown that where the ventilation has been carefully looked after, a fresh atmosphere secured, and water kept trickling down the timbering, the wood lasts for a considerable time. In some mines, pipes have been laid on, with small holes pierced in them, so that the water spirts out upon the timbering. Under any circumstances the timbering should not be exposed to much change in temperature, nor should it be allowed to be sometimes wet and sometimes dry.

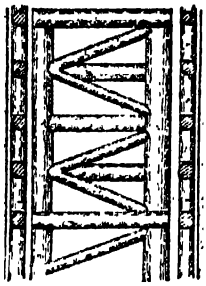

Fig. 152.

Chemical methods of various kinds have been tried for the preservation of mine timbers: soaking wood in brine, or in water containing sulphate of copper, as pumped from copper mines, or in which sulphate of iron has been dissolved. These processes are satisfactory for a short time only. The surface may be protected, and the salts may influence the wood, to a small distance beneath the surface, but cracks occur in the wood, and then the interior suffers from decay of some sort, which is not evident on the surface. The salts of zinc and of mercury have been recommended, but the first is not satisfactory, and the latter is too costly to be employed on large works.

Often, the kreosote process is applied, and without doubt, if care be taken to secure the absorption of the kreosote, it is a valuable one. It has been recommended to char the surface of the wood, by exposing it to the action of flame; if employed, the extremities of the pieces of wood to be buried in the ground should be perfectly charred.

The application of paint or of tar is not wise, since the decay may go on under the coating without its being observed.

Of the kinds of timber employed for mining purposes the following may be especially recommended, amongst the hard woods: white oak, evergreen oak, chestnut-tree, elm, and beech. White oak is the usual wood employed for timber work, on account of the dimensions of the balks which can be obtained and of its great strength; it resists, too, the bad air of mines, and if it is kept moist it lasts for a long time.

Evergreen oak is smaller than the white oak; it is chiefly found and used in the South of France. Chestnut-tree attains a large size, but it is destroyed by the bad air of mines, though it lasts well when placed under water. Elm and beech are employed where curving is required, either temporarily or permanently.

Resinous woods include the pine, the fir, and the larch, and several others but little used; they are distinguished by their long straight trunks.

These woods furnish long beams or straight pieces well adapted for timbering.

Pine is strong and durable when not exposed to warm or impure air, but it should be kept constantly wet.

The safest course is to employ ingenious and careful timbermen, and leave all the arrangements of the shafts to them. To experienced men—good carpenters—the mine manager should entrust the selection of the timber and its purchase. It is advisable to purchase timber at certain seasons of the year, especially such as requires storing. If possible, it is advantageous to roof the piles and secure good ventilation. The pile of timber should have a northern aspect, and the floor on which it is placed should be gently inclined, so as to facilitate the drainage of rain water.

It must never be forgotten that the decay of timber takes place more rapidly in a mine than when it is freely exposed to the influence of the air; therefore it is economical to secure the best possible ventilation. If any fungoid growth appears, or any cotton-like mould, the wood upon which it grows should be speedily taken away, as the growth is contagious, and spreads rapidly to some distance. The following summary, relating to timbering, is from Callon's "Lectures": "A piece of timber has in general to resist either a longitudinal pressure, which tends to break it by *crushing*, or a transverse pressure, which tends to break it by *bending*. In the first case it should be set up so that the longitudinal pressure is borne uniformly by all points on the transverse section, in a direction perpendicular to the section. If the pieces are long and liable to bend, their resistance may be materially increased by putting in struts from one frame to the next, or between the two legs of a frame. In the second case the length should be diminished as much as possible, and where at all practicable the ends should be inserted in grooves or *hitches*. In either case attention should be directed to giving stability to each piece by placing it in such a position that, if a small movement of the rock were supposed to take place in the direction of the resistance under consideration, the effect of the movement would be to tighten the timber and increase the lode upon it." *

Walling is a means of support in shafts, which is occasionally used in metalliferous mines, and very commonly employed in collieries. In the mines of the older rocks walling is not often required. In most cases the ordinary rock is compact enough to be trusted to stand without support; or where it is, from fissures or other defects, rendered necessary to protect the miner from falls of rock, it has been generally found sufficient to employ timbering.

The cost of timbering a large shaft will be about one-half the expense of lining it with masonry. But masonry will, if properly executed, last without any repairs for many years, whereas a timber lining will require constant attention and frequent repairs. We must distinguish between two different kinds of walling. One is building up a lining with dry stones, and the other is walling with stones carefully cut, squared, and cemented. The materials employed are rubble-stone, brick and hewn stone, Limestone, the Millstone

* "Lectures on Mining," delivered at the School of Mines, Paris. By J. Callon, Inspector-General of Mines. Translated by C. Le Neve Foster, D.Sc., and W. Galloway.

Grit of the Coal Measures, mica schist, and Slate rocks, which cleave well and form tolerably uniform blocks. Bricks, if properly made and duly burnt, possess several advantages. In walling a shaft, hydraulic mortar made thick should be used as sparingly as possible, so as to produce a continuous film of cementing material, between each course of stone; and care should be taken that no interstices should be left. If the stones or bricks are porous, they should be wetted thoroughly before being used. All spaces behind the walls left vacant by the removal of timber or otherwise, should be carefully filled with concrete or a mixture of *attle* (rubbish) and lime.

Masonry must be constructed in successive courses, in which to break joint with the preceding. The joints of one course should be so laid that the mass may be tied firmly together. For this purpose old timbers, cut so that their lengths are equal to the thickness of the masonry, may be used. The details of the art of building are beyond the purpose of this volume. Certain rules which ought to be observed in masonry underground have been given above. A few other points demand attention. When it is decided to wall a level, the masonry should be put in in a sufficiently strong manner. In masonry with parallel joints, the joints should be perpendicular to the pressure to be supported. In arches, the chord of the arc should be nearly at right angles to the pressure, and the thickness should increase as the arch becomes flatter. This applies more especially to collieries, the conditions of the metalliferous mine rarely demanding this attention. The following remarks are from the lectures of Mr. W. W. Smyth, and they are so full of the evidence of a practical acquaintance with the whole subject, that no abstract of them will serve the desired end:—

"In securing circular shafts, a couple of strong balks will be placed across the surface ground having the shafts between them. Then the foundation for the timbering of the shaft itself will be by putting in of *curbs* or *cribs* (circular frames of wood), which must obviously consist of a number of segments. When not required to be permanent, the segments do not require to be of any great thickness; and, if brickwork is to follow, they will generally be made of the same size as the bricks. These curbs used to be made of pieces of oak fitted together, or simply abutting, or one cut so as to overlap the other. Of late years the curbs have been made of cast iron. Behind these a planking of 9 or 10 feet planks is driven down, and if we are employing the method of *spilling*, these planks will be made to fit to each other very carefully. The curbs will be held together by stringing deals or laths. In this way the pit will be put down from the surface until you reach such a foundation as leads you to expect that you can base it on a satisfactory lining of brickwork. At this point the shaft will be widened, a little pit being sunk below for the accumulation of water during the process. The cutting will be done with pick, or hammer, or gad, or by any method except blasting, so as not to injure the ground. Then a curb is put in, now usually of cast iron, and above this will be built the walling. . . . . The precautions to be taken are that the bed should be very smooth and perfect, and that between the segments of cast iron there should be thin sheets of deal, so as to give a perfect joint when present together. . . . . As the *walling* is built up, all hollows are carefully filled, so that nothing can fall suddenly on

the workmen. In this manner one of the segments will be completed—then another segment will be proceeded with, in like manner below the first; and when the second casing of brickwork has been built up, the bracket of ground between it and the first will gradually be removed."

All this applies especially to the very superior shafts which are sunk in collieries. It must be remembered that where one shaft so thoroughly constructed is required in a large colliery, a dozen shafts may be, and often are, sunk in the more solid rocks of a metallic mine. It is, however, greatly to be desired that those shafts which are used for bringing up the ore, and which are the roads for entrance to, and exit from the mines, were more frequently built upon this system.

Mr. Smyth continues: "We have considered the method of securing shafts till we get down to a sure foundation. In some cases the masonry is put together on the surface and then lowered. In metallic mines, where the shafts are inclined, according to the inclination of the vein, this plan cannot be adopted; consequently where there is much water, it has to be kept down by pumping. Even where other portions of the shaft are secured in another manner, as with timber, there will be considerable advantage in securing the upper portion by means of masonry. Where in old shafts there was only a small area to be protected, our forefathers took a great deal of trouble in securing them, and this was by no means thrown away, seeing that otherwise the shafts would have collapsed at the surface. It is too much the case now in metalliferous mines that they are not walled up to the top of the shaft, and, consequently, this part is forced in, giving rise to expenses and dangers, and leading in some cases to loss of life, and in all causing considerable risk. The means of securing against this would be to line up, from a secure foundation, the sides of the shaft with stone-work. Then, when the mine is abandoned, the top might be covered up with a few large stones, and if it were required again the shaft would probably be found intact."

It now remains for us to notice the peculiarities which prevail in some of the more important districts. In the first place, the system common in Derbyshire must be examined. The description given by Farey in 1811* has been but slightly modified since his time. The following, therefore, is generally borrowed from him, a few notes only having been added to his very correct description, to adapt it to the modern practice.

It rarely happens in sinking mining shafts that the measures are so soft, after the corn-soil or day-earth is passed through, as to admit of being dug, until after the pick has been laboriously applied to loosen the measures, and more commonly gunpowder is necessary to blast and loosen them, even where decomposition, or perishing, so quickly follows exposure to the air, that a lining of stone, brick, or timber is necessary to keep the sides up, and prevent the shaft from "choaking" or running in; such soft or perishable strata are called "timbering measures" in many places. Shafts intended to be timbered, or lined with wood, are made square, or with parallel sides; while such as are to be ginged, steined, or lined with stone or brick are round or oval, in some few cases. For shallow shafts, a *stowe*, *turn-beam*, or *turn-tree*,

* "General View of the Agriculture and Minerals of Derbyshire, with Observations on the Means of ———." By John Farey, sen., Mineral Surveyor.

which is a rope—roll—with winch-handles for men to work, is erected over the shaft when dug as deep as men can conveniently throw out the stuff; and by means of tubs or close corves the water and sinking-stuff is sent up; but more usually, a horse-gin or horse-engine is erected near the shaft, having a large drum or rope-barrel, whence the mine-ropes are conducted to pulleys fixed over the shaft, by which means one barrel, or *corve*, ascends, while the other descends.

In sinking shafts in rock or hard measures, it often happens that the sinkers are obliged to work mid-leg deep in water. In such cases they bore or drill their blast-hole of a proper depth in the bottom; which done, a signal is given to the engine-tender (or *tenter*), above to work the engine briskly, to lower the water as much as possible. The sinker then throws a lump of tempered clay, about the size of his head, on the place where the hole is bored, pressing it firm all round to the rock, and into this clay he sticks a hollow open cone of plate iron, 15 or 16 inches high, with the small end downwards, over the blast-hole. The water is then laded out of this cone or funnel, and then the clay is taken from within it and out of the bore-hole, from which the water is also extracted, and the sides of it somewhat dried, by introducing rolls of soft paper or oakum, and in case water springs in at the bottom of the hole it is filled again with stiffly-tempered clay, which is driven very hard into the hole by a plug of wood which fits it, after which the clay is scraped out again and the hole dried; it is then charged with gunpowder in a tallow-papered cartridge, which is rammed, stopped, and primed by a wire, in the usual manner, and its fuse fired, when the sinker instantly slings himself to the drawing-rope, and on a signal made is drawn to the top, if the shot be set in a rock, but if in bind, though a larger charge of powder is used, he is usually drawn only 10 or 15 yards up the shaft, to wait the explosion.

Ginging and Timbering of Shafts in Derbyshire.—During the process of sinking, which has been treated above, the sinkers examine carefully the sides and bottom of their shaft, to ascertain such beds of hard and compact rock, coal, &c., as will stand permanently without lining, and in these parts the shaft is carefully made of its proper size, and no larger; while between such beds, it is cut out as much wider all round as to receive the stones, bricks, or timbers and planks which are necessary to support it like the lining of a common well.

In soft or timbering measures the sinking is carried down, as far as is judged safe, of a larger size than the intended shaft, when a curb, or flat ring of sound oak or elm, is laid on the bottom, on which the stones or bricks are built to the top; the sinking is then begun within this curb and continued down for 2 feet or more of that size, after which it is enlarged or bellied out to the size necessary to receive the ginging, and thus is continued down as far as is judged safe, when a new curb is laid, and the steining worked up to the contracted part, which is then cut out on the opposite sides of the shaft, so as to build up a pier or part of the wall in each, and firmly underpin it to the curb above. Other parts are then cut out between these, and the walling or ginging built up, and so on, until the whole of the stuff left to support the curb and walls above is removed and the ginging completed.

In some cases, where water comes into a shaft, from a particular measure between or above such as are compact and water-tight, a process called "stopping-out," "beating-out," or "framing-out" is resorted to for preventing such water from making its way into that shaft. In *ginging* shafts this is effected by making the shaft about 2 feet wider than necessary, building the wall, or ginging, very firm in mortar made of water-lime, like that from Barrow-on-Soar,* and ramming the space behind with well-tempered clay; carefully joining such clay to the water-tight measures below and above those where water is to be stopped-out of or confined in the measures.

In order to avoid the inconvenience of wet shafts, and the damage they occasion to the mine ropes, &c., spiral channels are often constructed behind the ginging, called "garlands," which intercept the water oozing from the measures, and convey it down, either to the bottom of the shaft, or to some level, or pump-cistern, whence it can be discharged, or pumped up, without descending to the bottom of the mine. When water is stopped-out of mine-shafts, or gates, by means of close wooden trunks or linings, as at Boggard mine, in Wirksworth, and other places, it is said to be *framed-out*.

Westgarth Forster† is especially earnest in recommending that plans should be carefully kept of every portion of the works in the mine, but he is loose in his description of the workings himself. A few facts are, however, of interest. He says, for example:—

"As mines generally occur in hilly, or mountainous grounds, and may be drained by means of levels, or *adits*, driven from the bottom of the hills, or mountains, it will be right to commence with the expense of driving those levels, per fathom, in the different beds which have been productive of metallic ores, and also in *plate beds*, or indurated argillaceous earths, in which ores have been seldom found to occur; but these last are better to drive in, than other beds of harder ore stone, therefore where there is a situation for draining the mines by levels, and a *plate bed* can be found to answer the purpose, it is preferable to any other.

"The measures generally used in *Alston Moor* for horse levels, are from 3 feet 4 inches to 4 feet wide, and 6 feet high, or thereabouts; and such levels may be driven at first, in a *plate bed*, to the length of 20 or 30 fathoms for from £1 to £1 10s. per fathom, exclusive of the charge for *arching*, *wooding*, and *railing*. But as the level proceeds further into the hill the incumbent weight becomes greater, the *plate*, *shale*, or *schist* more indurated, and the distance longer to remove the rubbish, and it may be necessary to increase the price per fathom to £3 or £4 or upwards. [It must not be forgotten that these were the prices prevailing more than sixty years since, and that consequently they have been increased in proportion to the general advance of the value of money.]

"It sometimes happens that a *plate bed* cannot be found to answer the intended purpose, when it may be necessary to drive in Limestone—hard Sandstone, or hazle. . . . . Such levels will require from £4 to £5, £6, or

* A blue lias clay found at Barrow-on-Soar and a few other places is considered superior to any other for sluices, locks, and piers, and other waterworks, on account of its property of setting immediately, even under sea-water, and continuing to harden.

† "Treatise on a Section of the Strata from Newcastle-upon-Tyne to the Mountain of Cross Fell, in Cumberland." By Westgarth Forster. 1821.

£8 per fathom, exclusive of placing the rails, &c., as before. When these levels have proceeded to the length of 50 or 60 fathoms, the miners generally require a circulation of fresh air, and for this purpose either a *bore-hole* may be put down, or a shaft sunk, so as to communicate with the farthest part of their workings. If there is a small stream of water at the surface it may be allowed to fall into a cistern, or tub, at the bottom of the *bore-hole* or shaft, and it has the effect of carrying down along with it a current of air. This contrivance is called by the miners a *water blast.* In some machines of this kind the constructors seem to have been of opinion that a great height was required in the water-fall; but numerous experiments have shown that an excess in height can never make up for a deficiency in the quantity of water. . . . .

"The measures used for *whimsey*, or horse-engine shafts, are generally about 4 feet 6 inches long by 3 feet broad. Whimsey shafts may be sunk to the depth of 10 or 15 fathoms, at from about £2 10s. to £3 or £4 per fathom, and after that from £5, £6, or £8 per fathom, exclusive of the charge for timber, walling, &c. &c."

Having described, as far as it appears necessary to do so, the construction of shafts, and securing them by lining, either with timber or with stone, we have to proceed to the consideration of the excavation of the passages, which may be driven through the ordinary non-productive rock, for the purpose of reaching the lodes, or, upon the course of the lode itself. In the first case, a considerable quantity of stone of little value is broken out; and in the second, the material broken out of the lode may be of real value. The latter, of course, is speedily sent to the surface, and there prepared for sale; and in the former the débris has to be deposited somewhere in the mine, where it may possibly serve some useful purpose.

In many of the metalliferous rocks, the ground is sufficiently firm to support itself, but it often occurs that there are defective pieces which demand support. Hence, even in metallic mines, it often becomes necessary to secure the sides of a level. In many of the metalliferous mines the rubble-stone, which has been broken out in excavating, serves for the purpose of securing the sides. If the rock is Granite or Elvan, or Trap, the pieces can be readily squared. If a schistose character prevails the pieces can be laid flat, and carefully built upon each other. It is important, whichever plan of walling is adopted, if the stones are not used dry, to cement them, in which case it is always the most prudent course to use hydraulic mortar made thick and spread rather sparingly, as a continuous film, between the beds of the successive courses, so that the spaces between the stones of the same course should be completely filled when the stones are pressed closely together.

It is frequently thought expedient to use timbering for securing the sides as being the more economical. Legs are, in this case, driven into the ground, the bottom of the level being made wider than the top, or "back," and the "cap" is fixed securely at each side to the top of the legs, and cross pieces secure the legs at the bottom; then lathes are driven in and carefully secured, Fig. 153.

When a gallery is pierced in ground of medium consistency, the miner is generally able to penetrate some distance without any support, and can

therefore build up the timber, as he advances. Supposing the four faces of the gallery, the roof, the wall, and the lateral partitions need support, it is necessary to establish, what is called, a complete timbering composed of *frames* and *laths*. Each complete *frame* is formed of four pieces, a *cap-sill* or *cornice* placed across the gallery, two *posts*, generally a little inclined, to diminish the bearing of the cap-sill, and a *sole-timber* placed on the soil, and serving

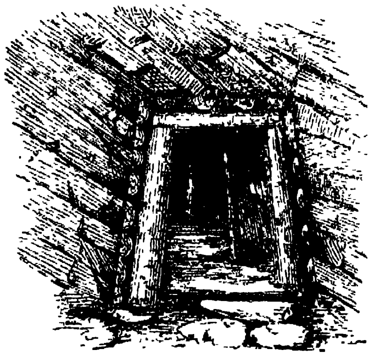

Fig. 153.

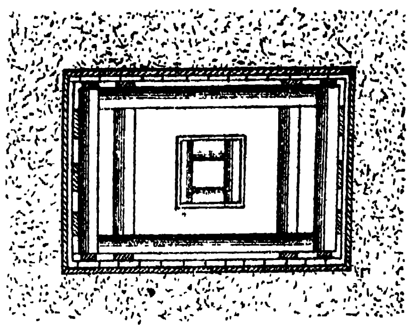

Fig. 154.

as a base to the posts, Fig. 154. Galleries driven into soft ground must be built up, and then the timbering is only used to facilitate the construction of masonry, strong enough to resist the pressure of the soil and check the infiltration of water. In such cases the arrangement of the timber is very simple, and generally entrusted to the miners themselves. The timbering consists principally of props placed perpendicularly from the roof to the wall, and wedged into their places by means of boards. When the gallery is a high one the props are placed according to the plan of the bed or vein, and sustained in that position by strong oaken boards, fitted into each other by notches, or so pressing against each other, that the greater the weight resting on the prop the closer becomes the pressure.

A sufficiently correct idea of a well-timbered gallery, and of the miners working—one in bringing down the rock from the end—and the other in loading a small truck placed upon a tramway, with the ore or rock, as the case may be, is shown in Fig. 155.

Fig. 155.

For the conveyance of the stuff broken out, in all rich mines, subterranean tramways are laid down. In Wales, however, in general, no other means are employed than a wheel-barrow run along the uneven floor of the rock.

Especial attention should be given, by the mine agent or engineer, to the timbering of a gallery, and if time is not of importance, it should be done in a fairly substantial manner. In some cases the necessity of placing supports arises suddenly. Then, of course, the miner must exert his thinking powers in determining how best to meet his difficulty. As soon as possible, however, the temporary supports should be removed, and good timber frames should be placed against the sides of the levels. The timbering should always be substantial, and be kept in good repair; at all times, if there is any tendency detected in the sides to thrust or press unequally on the timbering, the defective part should be immediately secured. It frequently happens, where the tendency of the roof to fall is considerable, that the rock broken out of the level can be built sufficiently solid to resist a general subsidence. The usual, ard perhaps the most effective, system is to build a good wall, especially where Slate stones are broken out; and unless they can be placed securely flat, as in their bedway, and spread judiciously, a little mortar must be used. The cementing of the Slate slabs requires the experience of a good mason. Then all spaces behind the wall should be filled in with the refuse (*gob-stowing*), making it as solid as possible. In many mines the infiltration of water holding iron in solution acts as a cementing agent, and eventually the mass becomes very nearly solid. These *pack-walls*, if judiciously built, will furnish a very secure support to any roof.

The foot-piece is obtained by cutting a large prop into two pieces longitudinally, and the *flat* face is laid on the floor of the level. The back of the *sole* is cut so as to receive the side props, their larger end being usually placed uppermost. They are always slightly inclined; the cap is adjusted so as to rest securely upon these props, and thus the *frame* forms a very firm trapezoid. After being fixed, the frame is tightened by driving in short pieces of wood between it and the rock, and above the collar, or cross-piece. In high galleries it is sometimes advantageous to arrange the *spreaders* so that they may form an air course above, or to floor the level so as to secure a water-course, or a good travelling road.

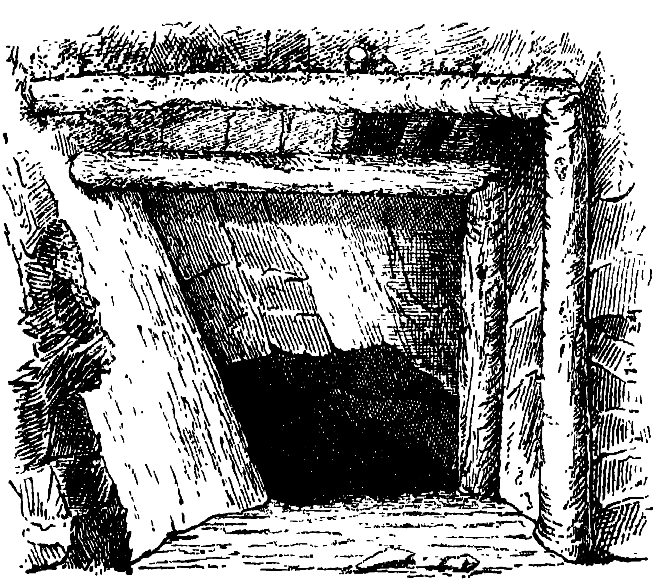

Fig. 156.—Props in Level.

When one side of the level is weak and the other is firm, one side-prop and a cap-piece are generally sufficient, Fig. 156. The end of the cap-piece is

placed in a hole cut in the solid side, while the other end is supported by a prop. When both sides of the level are firm, a simple *stemple* may be used for supporting the roof—then its ends will rest in holes (*hitches*), cut in each side next the roof.

After the lode has been worked away, support is often required, and frequently the space above the level is filled in with *deads* (*attle*). The weight of the filling up is then carried by *stull-pieces*, which are covered with boards (*stull-covering*), or poles (*lagging*), to prevent the stuff from running through. These pieces are placed at right angles to the plane of the lode, and rest in *hitches*, the depths of which depend upon the solidity of the walls. The hole cut in the rock must be of such a shape as to allow the spreaders to be easily adjusted, and then it must be carefully secured by a wedge well driven in, by which means it will be rendered less liable to be bent under the weight which it will have to support.

The character of ground necessarily varies considerably, and occasionally the miner passes from very hard and coherent rock to soft stone, and sometimes even to running sand full of water. This, however, is rare in metallic mines, although not unusual in coal mines. The adjustment under either of these conditions is, to arrange a set of lathes behind the poles and to drive them tightly, so as to fit together firmly, and thus offer the greatest resistance to the pressure.

Sometimes it is necessary to employ walling or masonry in a level, which is of course but slightly different from the walling of a shaft. Callon,* in his "Lectures on Mining," says, very correctly: "If the question be closely examined, it will be found that walling has not been employed as often as it might have been, with advantage. In order, however, that this remark may be correct, it must be understood to apply only to the case in which the walling can be made so substantial at first, that it will last for the whole length of time during which the gallery is to be kept open, without requiring notable repairs. . . . . On the whole, it may be said that the practice of walling ought to become more general as the mines become deeper and more extensive, and as the works below ground have to be kept open for longer periods . . . . but it does not seem probable that walling can altogether supplant timbering in the ordinary workings of a mine."

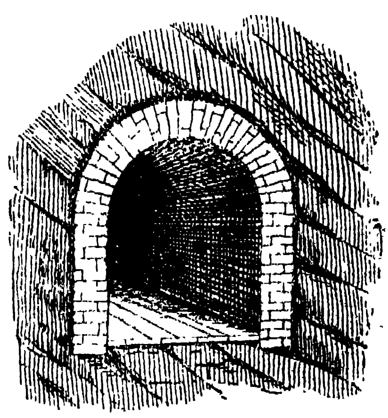

Fig. 157.—Walling end of Gallery.

Fig. 157 represents a gallery in which it has been necessary to employ masonry. In building a vault of this kind the miner has to be very careful in the choice of materials, whether quarry stone or brick be used. The piercing of a walled gallery is conducted in the same manner as a timber one; it is executed in sections, the excavations first being sustained by

* "Lectures on Mining," delivered at the School of Mines, Paris, by J. Callon, Inspector-General of Mines. Translated by C. Le Neve Foster and W. Galloway.

provisional timbering. When this is removed from the sides to make way for masonry, the removal must not only be complete, but all spaces left vacant by the removal should be carefully packed with (*attle*) rubbish, and in some cases it is advisable to use concrete.

In masonry with parallel joints, the joints should be perpendicular to the pressure; and, if arches are necessary, the chord of the arch should be at right angles to the pressure, and the imposts as solid as possible, the thickness increasing as the arch becomes flatter. The mass of masonry erected should be made strong by being tied well together, using binders where necessary, for which purpose old timber may be advantageously employed, cut so that the length of each piece is equal to the thickness of the masonry. If the roof requires supporting, caps may be used, their ends reposing in the side walls or on pieces of old timber placed horizontally, so as to distribute the pressure over a large space.

In the lead-mining districts of Wales, of Derbyshire, &c., the facilities for driving an adit level, or a water level, often supersedes the necessity of sinking shafts. The lead ore is generally sent out through the adit, and, for the conveyance of ore and stone, subterranean tramways are laid down, but frequently a wheel-barrow only is employed, and this is driven over the uneven rock floors of the level. Mr. W. W. Smyth has the following remarks on mining in Cardiganshire*: "Under favourable circumstances, shafts are sunk on the course of the lode, at convenient distances, connected by galleries or levels, at every 10 fathoms in depth, besides which short underground shafts or 'winzes' communicate here and there, from one level to another, and the orey mass is thus subdivided into quadrangular portions of convenient dimensions. The valuable part is 'broken' by 'overhand stopeing,' or a series of reversed steps, where the 'attle' or rubbish is thrown underfoot, whilst the miners thus rise from a lower to a higher 'level,' extracting as they proceed all the 'orey ground.' It is manifest, however, that by this method a certain degree of expensive preparation must precede the profitable extraction of the ore; and we find that in too many cases, either from want of sufficient means or knowledge, these preparatory operations are neglected, the seizure of the orey points made the first object, and a mine which might in better hands prove a lasting source of profit, is for a while forced to yield more or less of its treasure, at greater comparative expense, and is eventually crippled, abandoned, and left with a bad name to deter future speculators, or at all events in such a state as to require on their part a large outlay to restore it to a more favourable condition."

In Alston Moor, in peculiar situations, the miner is compelled to sink a *shaft*, but in most cases, owing to the hilly nature of the country, an *adit* or *level* is cut, which in this district signifies a passage cut in the solid rock large enough for men or horses, as the case may be, to pass into the mine workings. The usual dimensions of a level in Alston Moor is 3 feet in the bottom, gradually widening to the middle, and then being arched to the top, which is from 6 to 7 feet high. A horse-level seldom departs

* "On the Mining Districts of Cardiganshire and Montgomeryshire." By Warington W. Smyth, M.A. ("Memoirs of the Geological Survey of Great Britain," vol. ii. part 2, p. 668.)

from a very gentle rise, just sufficient to allow water to run along it. On the floor of such levels, wood or iron rails are laid for the purpose of facilitating the passage of the laden waggons. From these levels the vein is reached by *a rise*—a shaft worked upwards from one side of the level to the vein. At the bottom there is usually a short flat space left, 3 feet above the sole, or floor, of the level. The rises are cut at 15 or 20 fathoms apart, and the working is carried on alternately, this being convenient for the removal of the mineral or other matter broken down.

The *partnership bargains*, as they are called in Alston Moor, of the working miners with the adventurers are always regulated by the prospects of the vein. The parties undertaking any mine work are bound to observe the condition of commencing the work within a month from the date of signing the agreement. The work is to be regularly continued from day to day until the end of the term, and at least two workmen are to be continuously employed. One-fifth part of any ore raised is to be paid, as duty or rent, to the Greenwich Hospital.

The bargain includes labour in the mine—gunpowder or other necessary explosives—candles or lamps, and the charge for the conveyance of the ore or stone *to day*, *i.e.* outside the mine—and also the *dressing* (preparing) the ore for smelting. The price of working is always fixed by the *bing* of 8 cwts. Where the veins are thin, or where the ore is mixed with veinstone, a great quantity of valueless stone has to be removed for the purpose of having *drift room* to allow room for working the vein. All these circumstances have to be estimated in the cost of production. The average price in Alston for working lead ore is generally 30s. *per bing*. Four bings of ore are considered to produce a *fother* (sometimes *fodder*) of lead; for this the mine owners raise *five bings*, one being paid as royalty, or rent, to Greenwich Hospital. The late Mr. John Taylor stated that, judging of mining on a large scale, as much is paid for *dead* work—that is, for breaking out unprofitable rock—as is paid for raising the ore.

The miners work generally by rises 8 or 10 fathoms high, and have *stemples* or pieces of wood placed at two opposite sides 4 or 5 feet above each other. Workings continued downwards under the first drift are called *stoups*, and in them the vein is worked to the bottom of the drift. When the vein is productive below the horse-level, *a sump* is sunk to the required depth, which, if the ground is soft, is walled, but if the ground is hard it is left rugged and irregular. From the sump a drift is made, and the vein, if rich, is worked by headings and stoups, the work being drawn up the sump by a hand-whimsey. In a flat vein the workings frequently run to a great extent, the roof being supported by pieces of timber of sufficient strength.

In *Alston Moor*, after a mine is opened and appears to be productive, the miners take a certain piece of ground commonly called a *length*, in which they propose to raise ore for a certain time at so much a bing,* according to the richness of the mine or working. A *length* of ground is commonly either 12, 15, or 20 fathoms, and the price of procuring the ore depends much upon the hardness, the expense of drawing the stone or ore out of the mine, and the probable quantity of metal that can be raised.

* A bing is equal to eight hundredweight.

After working *a length* in a productive mine, the space is kept open with *deads*, leaving only *a rise*, from which another *drift*, called *a heading*, is made; the same operation being repeated until the top of the stratum, or the uppermost part of the vein, is reached.

The expense of drawing the ore or stone out of the mine when horses are employed is considerable, and depends entirely upon the length of the level or adit, and depth of the mine. In *Alston Moor* it is usually drawn out at so much per *shift*, and at some mines a shift consists of eight waggons, at others six only.

A miner's waggon, calculated for an *eight-waggon shift*, will contain thirty *kibbles*, and the capacity of each *kibble* is fourteen quarts or thereabouts. Waggons calculated for *six-waggon shifts* contain *forty kibbles*, making the shifts in both cases equal. The expense of drawing a shift in horse-levels varies from 3s. 6d. to 8s., including the filling, driving, and emptying the waggons, there being no allowance made for the difference of weight between the ore and the stone.

The dressing of the Lead ore is a division of the practical department, which receives considerable attention in Alston Moor. The separation of the ore from the Limestone, in which it is usually found, is not difficult, but the work required to bring up the value of the poor ores, and the smaller portion produced in working, is often so considerable, as to be remunerative only when great care is given to the work.

We presume that it will not be unacceptable to the reader to insert the following table, showing the value of lodes of different dimensions. Supposing a cubic foot of pure galena weighs on a medium 7,000 ozs. avoirdupois weight, a bing will then be equal to 14,336 ozs. We shall, according to the above, have as under, viz. :—

Inch wide.	Feet high.	Feet long.	Cubic feet.	Bing.	Cwts.	qrs.	lbs.	ozs
1 ..	.. 6 ..	.. 6 ..	.. 3 ..	1	3	2	24	8
2 ..	.. 6 ..	.. 6 ..	.. 6 .	2	7	1	21	0
3 ..	.. 6 ..	.. 6 ..	.. 9	4	3	0	17	8
4 ..	.. 6 ..	. 6 ..	.. 12	5	6	3	14	0
5 ..	.. 6 ..	.. 6 ..	.. 15	7	2	2	10	8
6 ..	.. 6 ..	.. 6 ..	.. 18	8	6	1	7	0
12 ..	.. 6 ..	.. 6 ..	.. 36	17	4	2	14	0
36 ..	.. 6 ..	.. 6 ..	.. 108	52	5	3	14	0

The Kind-Chaudron System of Shaft-Sinking.—Before we quit the subject of the mechanical operations necessary for the opening out of the mine, it appears necessary to give some account of this method of shaft-sinking in water-bearing strata. It must be admitted this system applies more generally and directly to the sinking of shafts in the Coal Measures; but there are cases in which the metalliferous miner will be glad of information on this system.

By the process worked out and improved by M. J. Chaudron, a Belgian mining engineer, no pumping machinery is used, and the water of the strata is not meddled with. The whole operation of sinking and tubbing is, with the help of certain tools and apparatus, done from the surface; not a man descends until the shaft is quite finished, securely tubbed, and absolutely dry. The water remains in the hole all the while, and, so far from being a hindrance or obstacle, is absolutely necessary for the working of the Chaudron system, as will clearly appear from the description. Moreover, the walls

or sides of the shaft are supported to a considerable extent by the water remaining inside, whilst under the old system the continued and increased flow of water, induced by the process of pumping itself, loosens the sides of the shaft, thus causing them to tumble in. This system, in fact, is not recommended except when much water is expected. In all other cases the ordinary ways of proceeding, if not quite so certain and efficacious in their results, may be cheaper.

1. *Preparatory Work.*—This consists in the erection of the buildings and sheds which may be found necessary, according to the special circumstances of each case; in the construction of the required machinery, and the preparation of the boring tools and others. The buildings should be arranged in such a way as not to interfere with the ulterior erection of the permanent ones, or with the winding machinery, &c., necessary for working the shaft when finished. A wooden building, with strong timber frames, will in most cases be sufficient. The power necessary is an ordinary winding engine, strong enough to lift the tools, and to withdraw the spoon or ladle used for extracting the débris. For a pit of large diameter, this machine may have a cylinder of 20-inch diameter and 40-inch stroke; the beating cylinder being a simple steam-cylinder open below, and of 3 or 4 feet maximum stroke. It contains a piston of about 30 to 36 inch diameter, the rod of which, passing through top cover of cylinder, is connected to one end of a strong braced timber beam. This beam is supported near the middle, and to its other end the tools for boring, &c., are attached. Steam being admitted by the attendant into the top of the cylinder, the boring tool attached to the other end of beating beam is lifted up, and the exhaust being afterwards opened suddenly, the tool comes down with a force in proportion to its great weight, crushing, at each blow, part of the bottom of the shaft. The beating cylinder is always and entirely worked by hand. The stroke of its piston is limited by a strong wrought-iron loop attached to the end of a braced timber beam, securely fixed in the foundation of engine-house. Between this loop and the beating beam an india-rubber and leather packing is introduced to deaden the blows and noise.

2. *Boring or Sinking the Shaft.*—The process employed during this part of the work is, generally speaking, that which, a good many years ago, was first successfully and repeatedly made use of in the case of borings of large diameter by Mr. Kind, the well-known German engineer and sinker of artesian wells. Four men only are required for this part of the work. The first tool used is a small trépan, or drill, consisting—say, in the case of a pit of about 15 feet diameter—of a heavy solid forging of 7 or 8 tons' weight, or thereabouts, according to circumstances, and measures across its lowest and widest part 6 to 7 feet, this being the diameter which it is intended to give to the first boring. This diameter is afterwards enlarged by a greater trépan, which has a weight of, in some cases, up to about 20 tons. The cutting part of the tool must, of course, be greater than the ultimate clear diameter of the pit.

The trépans on their lowest surface are armed with steel chisels or teeth, firmly fixed by keys in carefully-bored holes. Such a tooth weighs up to about ¾ cwt. The outside teeth have a special shape protruding somewhat over the solid body of the tool.

By means of connecting-rods the trépan is then attached to the beating beam. Everything is now ready for the work of drilling. The attendant, at the beating cylinder, admits steam over the piston, thus slowly lifting the trépan through a maximum height corresponding to the stroke of the beating cylinder. On allowing the steam to escape suddenly, the tool comes down with great force, doing its work of crushing the bottom. Three men standing on a platform take hold of a lever, before each new stroke, and turn the trépan slightly round its axis, so as to always work on a new line of the surface of bottom of pit. The length of the connections between beating beam and trépan must, of course, be gradually increased as the work proceeds. The first bore-hole made by the small trépan should always be kept ahead of the larger one by, say, at least 18 to 20 feet. All débris detached by the large trépan will thus fall into the smaller hole, and can be withdrawn therefrom by a special tool called "spoon," or "ladle," which is a wrought-iron riveted cylinder suspended in a wrought-iron fork, and of a somewhat less diameter than the first boring, so as to allow of its being lowered into it without difficulty. The bottom consists of two flaps which open upwards when the tool is lowered to the bottom of bore-hole and worked a few times up and down through a short distance by the aid of the winding-engine. They thus allow the débris, previously formed by the working of the trépan, to enter and fill the spoon. On beginning to wind up these flaps close immediately, and the contents can be safely landed on the surface. The average progress of sinking by these means varies in ordinary strata between 2 and 4 feet per day.

3. *Tubbing.*—After having bored the shaft to the desired depth and diameter, the next most important operation is the putting in of the tubbing. M. Chaudron's tubbing consists of strong cast-iron entire rings or cylinders having inside flanges at top and bottom, and a parallel strengthening rib in the middle of their height. The total weight of tubbing for a shaft may easily go up to, or exceed, 1,000 tons, and the very simple and ingenious invention of M. Chaudron, for the lowering of this enormous weight, consists in attaching a temporary bottom, in a water-tight manner, to a special inside flange of the lowest ring but one. By this means the ring in question is immediately changed into a vessel, and able to float on the surface of the water in the shaft. Nothing is now easier than to add ring after ring, taking always the utmost care to render all joints absolutely water-tight. Special arrangements have, however, to be made to secure the sinking down of the tubbing, which would otherwise remain floating. This is done by erecting, and gradually increasing in length, a column of pipes fixed to a hole in the temporary bottom. The pit water, finding its level in this equilibrium pipe, can then be allowed to enter by cocks provided for this purpose, and charge the tubbing to any degree required; care must only be taken not to allow one of these cocks to remain open, and sink under the surface of the water level.

To cut off all communication between the inside of the tubbing and the overlying water-bearing strata, the shaft should have been sunk to such a depth as to pierce the water-bearing strata by some little distance, and to enter into solid and unbroken ground. On this latter the tubbing is allowed

to come to rest, and in order to get a water-tight joint between the outside and the lowest part of the tubbing, and the surrounding rock, M. Chaudron conceived the idea of giving to the lowest ring the construction of a gigantic stuffing-box. This consists of an outer ring, having at its lower end an outside flange, inside which, and loosely suspended by bolts, is a ring of less diameter, likewise provided at its lower end with an external flange. These two external flanges confine a space which, before the introduction of the stuffing-box into the pit, is filled carefully with moss or a similar material, retained by thin thread or wire-netting. As soon as the tubbing touches its ultimate resting-place at the bottom of the pit, the whole of its enormous weight is gradually allowed to compress the moss in the stuffing-box and thereby immediately, and for once and all, cuts off the water from the upper strata.

4. *Cementing.*—In order to still further secure the permanent tightness of the tubbing, and in order to support it completely and all round, the space remaining between its outside and the wall of bore-hole should now be filled up with concrete or mortar. This operation is executed with the help of a special tool.

5. *Withdrawing the Temporary Bottom.*—In order to do this it is necessary to extract the water inside the tubbing. This should, however, not be attempted until the cement outside has had full time to settle and harden. It is easily and quickly done by a bucket, and by the help of the engine previously used for the sinking. The next operation is the removal of the equilibrium column, and of the temporary bottom, to which it was attached. The joint made by the moss box can then, if desirable, be supported and secured by further precautionary work, such as the introduction of a wedging crib and masonry. After this the application of Chaudron's system is at an end, and sinking and mining operations are begun in the ordinary manner.

One other ingenious method of sinking shafts must be mentioned. M. Triger, engineer in the Department of Maine and Loire, had the idea of making a well in the very bed of the Loire by means of compressed air. A cylinder of thin iron, which served as a cutting-machine, was sunk into the alluvium; it was separated into three compartments by horizontal partitions. The upper compartment remained always open, the lower compartment was the workshop, and between them was the middle one, which served as a chamber of equilibrum, designed to be put in communication with either the compartment above or the one below. The things being so disposed, they forced into the bottom compartment air compressed by a vapour-machine without intermission. This air drove the water up a tube, of which the lower part was buried in the bottom of the excavation, and of which the upper part was raised above the cylinder. The workmen were then able to penetrate the first apartment and open the second, which was afterwards hermetically closed, and in which the air of ordinary pressure was put in communication with the compressed air in the third. Having arrived in the third compartment they excavate the sands, and cause the machine to descend. As they accumulate the sands excavated in the middle compartment, they have only to remove them by shutting the communication with the bottom and opening that of the top. A pressure sufficient to balance the

exterior waters is maintained during the work, without sensibly incommoding the workmen. This ingenious proceeding has received numerous applications. It is evident that wells dug in the water-saturated soils must immediately be cased, that is to say, covered with a casing of wood or metal, solid and impermeable, which is able to resist the infiltration and pressure of the waters.

A plan similar to this was employed by Sir Isambard Brunel in the construction of one of the piers, in the bed of the river Tamar, for the Royal Albert Bridge, at Saltash.

Drawing Stuff.—When the mine is in its earlier stages of exploration—or rather of sinking—the stuff is drawn by means of the simple windlass, which is turned by either one or two men, and the ore is brought to the surface in the ordinary iron kibble, or sometimes, in tubs. The precautions necessary in this case are attention to the strength of the ropes and the good condition of the tackle. In many cases it is necessary that even those small shafts should be carefully timbered, as if the sides of the shaft are loose and liable to break out, the miners might otherwise suffer from the fall of the broken masses.

The miners in sinking a preliminary shaft, in most cases, use gunpowder or some other explosive; and then the hole having been bored and charged, preparations are rapidly made for ascending, the fuse is lighted, and the miner drawn with all speed to the surface. The following interesting circumstance illustrates the perils attendant on work of this character. Two miners were at work in the bottom of a shallow shaft of this description, in a mine in the Liskeard district. Everything was prepared for blasting, the fuse was ignited, and both men jumped into the bucket, holding on by the rope and calling to the surface to be hauled up. This order was not obeyed, and presently they discovered that one of the men, who should have been at the windlass, had left his place, and the one man still at the mouth of the pit was not strong enough to wind up the two men. No time was to be lost; the younger man jumped from the bucket, saying, "You go up, comrade; you have a family, I have none." The man left in the shaft threw himself on the ground, beside the burning fuse, and seizing a board, placed it upon his body, and waited in an agony for the explosion to take place. In a little time it did so, with stunning effect on the prostrate miner, and the fragments fell in a shower around him. Resting for a minute in suspense, he was surprised to find he was not hurt, and presently he was drawn rejoicingly to grass. Many similar examples of heroism amongst the working miners might be mentioned.

As the shaft increases in depth the "haulage of stuff" is increased, and the horse-whim is substituted for the windlass.

Horse-whims or gins may be constructed of several different patterns; the whim represented, Fig. 158, is constructed for heavy work and with a view to durability.

A is the span beam, with a bearing of 39 feet 16 inches in depth in the middle and 8 inches thick; B is the horse-arm, 35 feet 8 inches long, consisting of one piece, 12 inches by 7, passed through a mortice in the axle of the drum D. If this arm is required to stand the strain for a great length of

time it is trussed, and consists of two pieces, each 1 foot 2 inches by 4 inches, notched into and bolted to two opposite sides of the axle D, where they measure across from outside to outside 2 feet, and then the truss is gradually narrowed near the ends, where they measure 1 foot 4 inches. They are blocked apart and bolted together through the blocks between the centre and the extremities. C is the drum, in this case 9 feet in diameter and 2 feet 6 inches deep, divided into two parts by a fillet round the middle of the cylindrical part of the drum to separate the ascending and descending ropes. The ropes are prevented from working off the drums by horns projecting around the top and bottom, twelve in number, made of 4 by 4 inch stuff, and jutting out about 10 inches, the inner side of the projection being sloped off. D is the drum-shaft, 13 feet 6 inches long and 1 foot 2 inches square; to this the horse-arm B is securely bolted at 4 feet from its top, and steadied by stays of 4 by 4 inch scantling from its lower part; to these stays the driving-boys tied one end of a small cord, which served as a rein

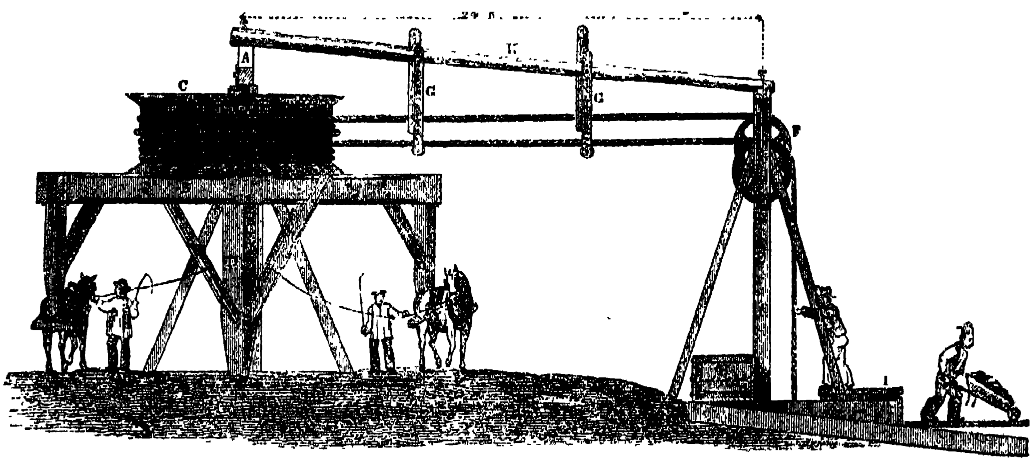

Fig. 158.—Horse-Whim.

to the horses, as shown in the engraving. Above the horse-arm, and resting on it, the drum is secured by the axle passing through it; the frame of the drum is made square in the centre for that purpose; the lower frame of the drum is steadied from the axle, at right angles to the horse-arm by stays similar to those last described. The axle rotates on two spindles of 2-inch round iron, one end being squared and turned both ways, at right angles, to secure a firm hold in the column. The top spindle works in a socket formed by straps bolted to the span-beam, and the bottom spindle works in a bell-metal cup. The top of the axle has one hoop, 2 inches by ½ inch, driven on after the spindle is fixed; and the bottom of the axle in like manner has two hoops. The weight of the top spindle was 28 lbs.; the bottom spindle, 25 lbs.; the straps for the top spindle, 18 lbs.; the three hoops, 21 lbs.; and the brass or bell-metal cup, 13 lbs.

The horses were harnessed to beams attached to a perpendicular piece, 8 inches by 10 inches, its top forming the end of the truss of the horse-arm, from which it was pendent; it was also steadied thereto by means of braces.

The harness-poles were made to revolve on a spindle at the bottom of the perpendicular piece last named, whereby the horses could be turned round and proceed in the opposite direction, to reverse the action of the machinery, which was necessary at every ascent and descent of the ropes—the one ascending as the other descended, and *vice versâ*. It is, however, more convenient to construct the machinery of the gin so that the alternate ascending and descending action of the ropes can be effected without the necessity of turning the horses round.

The span-beam A is supported at each end by a triangular frame, the base of which is 13 feet long, and is steadied with props. E is the pit-frame placed on each side of the shaft, at a distance of 24 feet 6 inches from the drum-shaft. This carries the head-gearing or frames, in which are mounted the pulley-wheels or sheaves, which are of cast iron, 3 feet in diameter, and weighing 1 cwt. 3 qrs. The spindle upon which the sheave revolves is of wrought iron 2 inches diameter, and worked in a bell-metal box or plummer-block, weighing about 3½ lbs. K is a pole, of which there are two, called jackanapes-poles, because they carry what are technically called the jackanapes, G G, whose use is to keep the rope straight in passing from the drum to the head-gearing, and they have small friction rollers for it to work upon. These jackanapes are pendulous, and therefore they vibrate or yield as the ropes move, which is necessary, because the ropes continually change their levels as they wind round the drum, or *vice versâ*. H shows the trough into which the kibbles empty themselves when tilted, from which trough the ore is passed into proper trams, to be transported to the dressing-floors. I shows the platform, made to run upon flange-wheels worked upon rails, whereby it can be drawn over the pit-shaft to cover it when necessary, for greater security in landing the skips full of ore or rubbish, as they are raised to the surface; the skips are then rolled away on temporary rails and emptied of their contents. The pit-frame and head-gearing are made of oak, the frame of the drum of oak, and the covering of elm; the jackanapes-poles are of larch, the horse-shafts of ash, and the rest of the gin of Dantzic timber.

For the greater preservation of the ropes, they should be tarred and payed over with coarse canvas, also tarred where there is an excess of friction. Some such covering is requisite for economy's sake, as the wear upon some parts of the rope is considerable. It may be worth remarking that wire ropes would be applicable with advantage to the purposes under consideration—not only on account of their greater durability—but to prevent the possibility of wicked persons cutting or otherwise injuring the ropes, to cause accidents by their breaking when loaded. Such circumstances have occurred unfortunately, and ropes which have wilfully been cut have broken at a time when several men in a skip have been suspended by it; whereupon they fell to the bottom of the shaft and were killed. This, happily, is not of frequent occurrence. Too great care cannot be exercised where there is a large body of men congregated together, some of whom may be apt to indulge vindictive feelings.

At the time of writing these remarks a dreadful accident has happened at

Wheal Agar tin mine, near Redruth, in Cornwall. On Wednesday, the 17th of August, 1883, thirteen men were being raised from the 195-fathom level to the surface. The cage in which they were riding had reached the landing-place, when one of the men jumped off, and thus saved his life; the wire rope by which the cage was suspended then suddenly broke, and twelve men were precipitated to the bottom of the shaft, and consequently lost their lives. The chief agent stated at the inquest that, as some imperfection had been detected in the ordinary whim rope, which was generally used for raising the men, it was changed for the capstan rope. Eight men went to the surface safely immediately after the change of rope. Then "a party" went down, and the next batch went up. "When they went up there were thirteen in 'the gig,' ten on the inside and three on the top. They went up about seven o'clock from the 195-fathom level. They had reached the surface, and Henry Carbines jumped out safely." In the drawing rope (that is, the whim rope) they found one of the strands broken, and the rope was bad for from 20 to 30 fathoms in length, the strands having coiled back. It would appear that not more than eight men were, by the regulations in force at Wheal Agar, permitted to ascend in the cage at the same time, "timbermen, shaftsmen, or pitmen being excepted, these being allowed to ride on the top, to see that the shaft and the timbering, &c., was all right." In this case it is evident that the proper amount of care in examining the rope had not been taken. The evidence of the engineer—surveyor-in-chief for the Board of Trade—states: "I consider the breakage was caused through the rope not being sound. Several of the wires were very much corroded. I can form no opinion as to how long they may have been in that state, but in the ordinary course of events some considerable time. I must say I think many of the wires which were corroded would not have been visible to a mere external examination. In addition to the rope being fractured, owing to corrosion, it was injured in being worked at a strain of 20 tons. If the rope were a good one I should work it up to a strain of 5 or 6 tons; *but I would not work it at such a strain in raising men.* If there had been a 'kink' in it, that would have made it more liable to break. I attribute the accident to the corroded state of the rope, coupled with the fact that it had been used to raise 20 tons."

The Inspector of Mines said he "deprecated the use of grease and oil as lubricants for such a rope, as they tend to hide defects." This, under ordinary circumstances, is quite correct; but in the case of Wheal Agar these lubricants—grease or tar—especially over that part of the wire rope which was attached to the skip, were useful in protecting the wires from the action of the copper water, into which the loose portion of the rope dipped when it was at the bottom of the mine. The result of the coroner's inquest was a verdict of "Accidental death." It is seriously hoped that this sad accident, and the facts brought out in the inquiry, will lead to such precautions as will prevent a recurrence of any similar accident.

This will be the proper place to insert some information relative to the tenacity of wires and of the conditions under which wire ropes may be safely employed. The following table, showing the circumference of wire ropes, the weight per fathom, their breaking strength in tons, and working load

in cwts.,* constructed with great care, cannot fail to be useful as a guide to the miners :—

Girth in Inches.	Pounds Weight per Fathom.	Breaking Strain in Tons.	in Cwts.
1	1	2	6
1¼	1½	3	9
1¾	2½	5	15
2	3½	7	21
2¼	4½	9	27
2½	5½	11	33
2¾	6½	13	39
3	7½	15	45
3¼	8½	17	51
3½	10	20	60
3¾	12	24	72
4	14	28	84
4¼	15	30	90
4½	16	32	96
4¾	18	36	108

The following table again shows the sizes, weights, and strength of *flat wire ropes* and of equivalent *flat hempen ropes*†:—

Hemp.		Wire.		Breaking Strain in Tons.	Working Load in Cwts.
Size in Inches.	Lbs. Weight per Fathom.	Size in Inches.	Lbs. Weight per Fathom.		
4 × 1	16½	2⅛ × ½	9	16	36
4½ × 1⅛	20	2½ × ½	10	18	40
5 × 1¼	24	2¾ × ⅝	12½	22½	50
5½ × 1⅜	26	3 × ⅝	15	27	60
6 × 1½	28	3½ × ⅝	18	32	72
7 × 1⅞	36	4 × ⅝	20	36	80
8¼ × 2⅛	40	4½ × ⅝	22½	40	90
8½ × 2¼	45	5 × ⅝	25	45	100

Iron wire, as a rule, has been employed in the manufacture of ropes; steel wire is now preferred, and until recently the wires were subjected to a considerable amount of twist in the construction of the rope. This torsion necessarily lessened the tensile strength, the strain not being always in the direction of the length of the wire. According to the amount of twisting, so would necessarily be the liability to fracture, across the length. The wires should, in the construction of either a round or a flat rope, be laid carefully together, and subjected to no more twist than absolutely necessary for firmly securing the strands. It will be obvious, after these remarks, that it is a matter of equal importance, to wind a wire rope on the largest drum which can be conveniently used. When first wire ropes were introduced in our mines, they were placed on the same drums which had been employed

* "Records of Mining and Metallurgy." By Phillips and Darlington. See also "De l'Extraction dans les Mines du Cornwall," par M. L. Moissenet.

† Mr. Stephen Eddy, of Grassington, states that the difference between a wire and hemp rope, working under similar conditions, is as 5 to 3 in favour of the former. (Royal Cornwall Polytechnic Society's Report for 1856.)

for hemp ropes. The consequence was, that it was not unusual to find the wire rope upon the drum presenting the bristling points of broken wires.

In connection with winding machinery, much has been said of the advisability of using safety-catches, by means of which, in the event of the fracture of the rope, the load, whatever it might be, should be prevented from falling. Safety-catches have been introduced of several descriptions, the principle being nearly the same in all. When the rope, whether of hemp or wire, breaks, arms which were held free so long as the weight was suspended from them, fly out, and catch the guides placed at the sides of the shaft. These have been used with some advantage in many of our collieries. They have, however, this objection: safety-catches being introduced, the condition of the ropes appears often to have been neglected, and they have been trusted to run beyond the usual period allowed.

Another objection to the use of safety apparatus of any kind, when the miners are being raised or lowered, is this: while the cage containing the men is travelling up or down the shaft, if the rope breaks, and the catch is brought immediately into operation, the momentum of the falling mass being suddenly checked, the miners receive a blow equal to that of the weight multiplied by the velocity, which has in many cases resulted in serious consequences. The only safe course is, to reduce the velocity of the falling mass *slowly*, and gradually to bring it to a state of rest.

Shafts in metal mines, being used for various purposes, require especial attention, according to the uses for which they are intended. In many cases a special shaft is devoted to the pumping arrangements only. For this purpose the sides of the shaft should be carefully protected, and where the rock which has been cut through is not thought to be sufficiently firm, good timbering must be put in, and in many cases a lining of masonry will be found to be, from its greater durability, the most economical. A ladder-way is placed in the engine-shaft, to enable the engineer and his men to inspect the pump work. Other shafts also are employed for pumping, and for raising the ores. Where this is the case a strong division should be put in it, to protect the pumps from the falling of masses of ore or stuff from the kibbles or skips. Many shafts are especially constructed for the use of the miners only in proceeding to and from the levels in which they labour. We sometimes, however, find such shafts used for pumping and winding; where this is the case, the divisions should be judiciously designed and carefully constructed.

In all shafts every precaution should be taken to protect the miners from danger, especially from the fall of stones. A comparatively small stone falling through a hundred feet or more, acquires by its increased velocity a force which is sufficient to cause death. The usual practice is to place on one side, so as to cover a portion of the shaft, a pent-house, beneath which the miners can retire when kibbles laden with ore or other things are being raised or lowered. To reduce the risks as much as possible, pieces of wood, called "striking deals," are sometimes placed under the platforms or support of the pent-house. These being placed at an angle serve to guide the kibble in its ascent, so that it passes on safely to, and through, the opening at the top of the shaft. It is often the practice to divide a shaft for pumping and for

"winding," or "drawing stuff," with a division for a ladder way. Where this is done the ladders are placed in the middle, and to protect the miners the side next the division employed for winding should be carefully boarded through its whole length, but on the side next the pumps it may be left open, except at intervals, where a slighter separation is advisable.

Kibbles are the buckets in which the ore is placed for the purpose of being drawn to the surface. These are made at the local foundries of the best plate-iron, of great strength and resistance, as they are subjected to much rough usage, and in swinging in the shaft they are liable to severe blows against the sides of it. Kibbles are still used in small mines, or in shafts which are not of great depth. The kibble is usually suspended by a chain for a certain length, which is then attached to either a hempen rope or a wire one. The size of kibbles varies considerably in different localities, this being often a matter of caprice, which is of course regulated by the amount of work which has to be accomplished. Their capacity varies from 1 to 25 cwts.

"*Winze Kibbles,*" used with a windlass and tackle, are usually about 14 inches high and 12 inches diameter, holding about 1½ cwt. In Dolcoath mine, kibbles of a large size are worked in some of the old irregular shafts. These are often 4 feet high and 3 feet 6 inches wide.

In some mines the amount of "stuff" drawn by waggons and loaded into the kibbles is very great. At the Lisburn mines, in Cardiganshire, 100,725 kibbles have been drawn to the surface in one year, and at Polberoo mine, in Cornwall, 174,831 kibbles were hauled in the same period.* The use of the kibble is gradually passing away, the "skip" travelling in "guides" being in every way an improvement. A larger weight of ore can be drawn in the same time, and with a proper amount of care the risk from breaking or from the falling away of stones is reduced to a minimum. Kibbles are still used in the shafts of old mines, which are often much inclined and very irregular. The lower side or the foot-wall of the shaft is generally lined with timber "bed-plank" to reduce the friction. Under any arrangement, however, the wear on both the kibble and the flooring is very great, the friction between the two being enormous. Breakages are also very frequent, the strain on the chains or ropes being excessive, and the shocks severe. It is the wiser course, as being in the end the most economical, to straighten the shaft as much as possible, and to put in guides, or shaft railways. Upon these skips can be run, with considerable advantage as it respects both economy and safety.

Skips vary greatly in their construction and in their manner of being guided, so we will take for example those used at Levant mine, St. Just, Fig. 159. The faces of the skip are united with strong rivets. The long sides are bent at right angles, and the bottom riveted underneath. The plate of metal which serves as door is strengthened by two strong bands, and is fastened by a horizontal bolt and a vertical bar or needle, the eye for the bolt being firmly riveted to the bottom of the skip. This bolt is placed, or removed, by a blow from a hammer. Another mode of fastening is by means of a vertical iron fork the length of the door, which slides into two projections in the bottom of the skip. This is held firmly by a sort of handle which wedges the top of

* "Records of Mining and Metallurgy." By J. Arthur Phillips and John Darlington.

the fork. The miner who receives the skip at the surface, with two blows of his pick, can turn the handle and raise the fork.

The handle by which the skip hangs is sometimes arched, but more often it is bent into right angles, to leave the entrance entirely free when it is turned over. The axle on which the handle turns is held by a plate of metal and five rivets. The skips will generally contain about 12 cwts. of stuff, or sometimes as much as 13 cwts.

The different modes of guidance adopted for the skips depend principally on the construction of the shaft. Where the shaft is vertical, the skip has no wheels; but it is kept in position by bars of wood. When the shaft is not vertical, but following the course of the lode, the skip is made to run on guides which form grooves. The wheels are of cast iron encircled with iron of a better kind, with rims and four spokes of hammered iron, and the nave is of cast iron. They should be kept as small and light as possible.

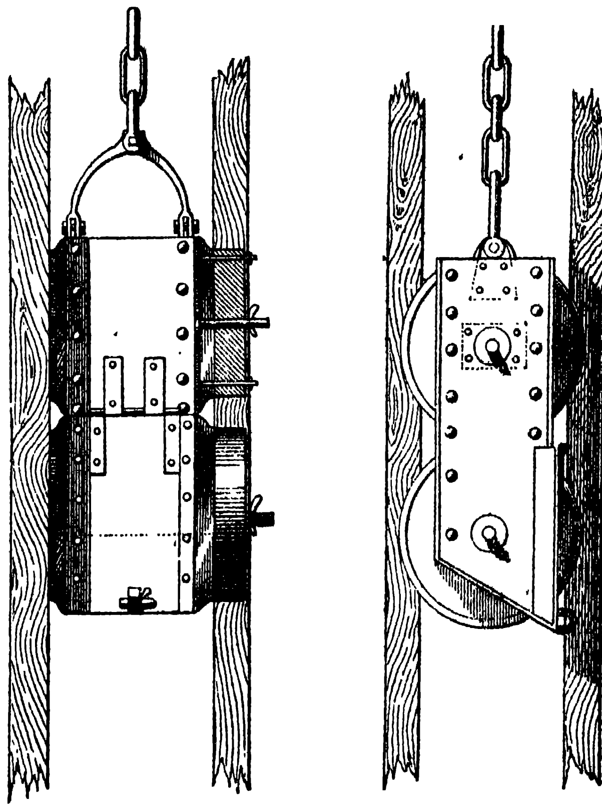

Fig. 159.

Skips of sheet steel might be used with great advantage on account of their lightness. The extra expense would be compensated by their durability. If safety-catches were generally employed, and great care and attention paid to the proper maintenance of the cables, a skip would wear for a long period. A pair of skips is generally kept in reserve in case of accident, and it is estimated that each drawing shaft will, as a rule, require sometimes one and sometimes two pairs in the year.

Skips are now generally raised by means of wire ropes. Unless the guides or railways are carefully put in the friction is considerable, and it is not often that a speed of 350 feet a minute is exceeded. In highly-inclined shafts the skips are always fitted with wheels, but simple guides will suffice, as already said, when the shaft is vertical and kept in good order.

Generally the skip is filled at the upper end, which, when filled, is closed by a hinged door. This door is secured by a catch, while it is travelling, but on arriving at the surface the man who receives it, called a "lander,"

brings it over the waggon, and, opening the door, allows the ore to slide down the sloping end.

In mines of a superior class a pair of *cages* are sometimes used, similar in many respects to those employed in the collieries. These are arranged to admit the waggons (Fig. 160), to run in from the "end" or to be brought close up to "the face of the work."

These waggons may be suspended from the rope by iron hooks or bands. Loops are made one on each side of the waggon, as at A A. These loops receive the hook of a chain made of ⅝-inch iron attached to the end of the rope by a shackle. The wheels and axles are attached for the purpose of running the trucks along the temporary railroad laid from the face of the workings along the level, and also upon a similar railway above ground, from the top of the shaft to the dressing-floors.

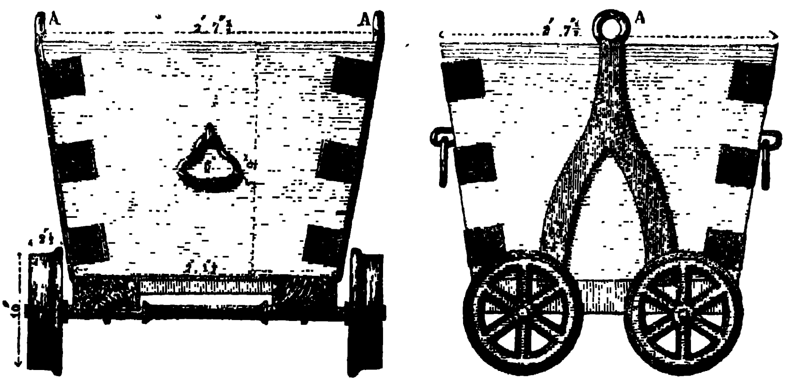

Fig. 160.

The dimensions of a pair of such waggons is given in the drawings, but they vary considerably in this respect. The ring A is adjusted so that if necessary the waggon can be slung, but when run into cages this is not necessary. By this arrangement much greater speed is attained, as the waggon is loaded near the working place of the miner and the load is not disturbed until it reaches the surface.

In the tin and copper mines the drawing of mineral through the shaft requires much attention. The rate of drawing is constantly varying—sometimes it is from shallow levels, and sometimes from very deep ones. In this country the levels go off from the shafts at intervals of 10 or 12 fathoms, and in many of these levels there may be active workings. In some mines the accumulation of mineral is large in the levels, in others it is small. Frequently the mineral is allowed to accumulate in the levels, impeding the passages of the mine and interfering with the ventilation. It is not unusual, where the ground is worked by *tut work*, and it is often convenient, to have adjoining the shaft some means of storing the ore. This space is termed "*a plat*," the variety ordinarily used being called "*a tip-plat*." Where the level opens into the shaft, for a distance of 2 or 3 fathoms back from the shaft, a *stope* is generally taken about the same height as the level, and the rails used will be continued over this by a framework of timber. This is useful, as the waggon will be run on to this framework, and the material tipped into the space below, until the drawing machinery is ready to

raise it. The angle of the upper portion of the level above the plat should be taken off, so that the rope may not be cut when the kibble is drawn aside. When such a plat has to be carried out in ground of a difficult character, it is usual to put in the timbering temporarily at first, then, when the level and stopes have been fully extended, the plat is formed and the timbering completed. A plat is begun half the height at first at the two ends, leaving a solid pillar in the centre. After driving a short distance and the roof requires supporting, leg pieces should be put in, which must rest on longitudinal sole pieces. Then, when the two sides are driven as far as required, the central pillar may be taken away and permanent timbering put in.

It is essential that a well-contrived recess for the skips should be constructed. The skip not being arranged so as to leave the guides, there is a method adopted at each recess, sometimes of chains, sometimes of bars of iron hinged against the recess, and of a height equal to that of the skip. These being reversed or those extended, the skip rests on them, and can be held at any level the *filler* requires.

As a rule the loading is done as if for kibbles—the large stones of ore are thrown in by hand, then the small pieces are lifted with a shovel. Two fillers are employed at this work.

Fig. 161 represents a recess of this kind in Wheal Buller. The veinstone of chlorite and fluor-spar, being soft and friable, breaks into small fragments, and admits of a hopper being placed, with a trap, which accelerates the lading. The skip, when it arrives on the bars, has a covering placed on it at the hinges, the trap is raised, and the filler has only to direct the flowing of the ore into the vessel. This arrangement is certainly advantageous when the nature of the stuff will permit of it.

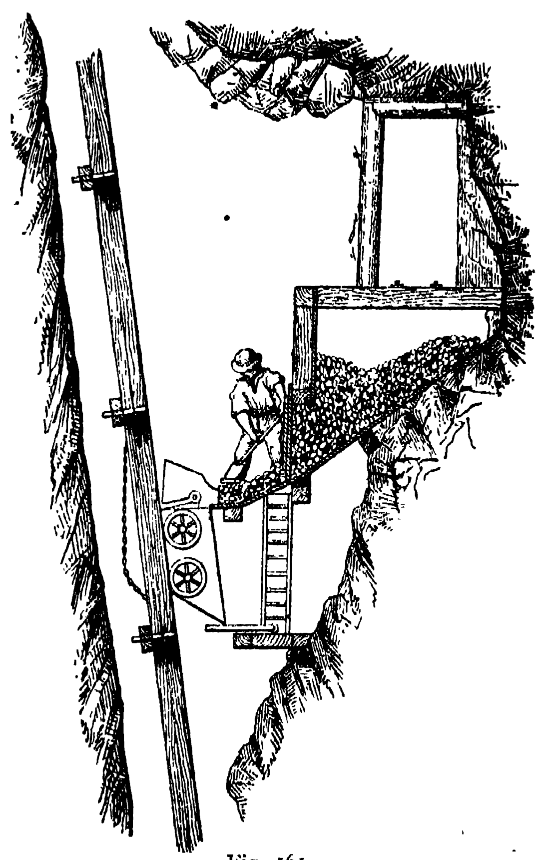

Fig. 161.

The recess for the skip above ground is sometimes divided into two parts, the one movable on hinges and the other fixed projecting over the waggon. Two bars of iron, supported on the guides, form the head of the inclined plane; the skip is turned over and emptied in an instant. As soon as it is empty the double hook is taken away, the door beaten down and fastened. The lander waits the signal from below, the skip is a little raised, the workman hastens to release the skip, and the movement—up or down—commences. It

has been stated that the distance between the levels, which in 1778* we are told was generally 8 fathoms, has been increased to 10, and occasionally to 12 fathoms. There are no good reasons why any fixed distances should be established for the distances of the levels; they should in all cases be regulated by the character of the lode and the facilities of winding in the shaft. When lodes are large, with short deposits of ore, a less distance than 10 fathoms between the levels may be very advantageous, but in many cases wider distances may be judiciously adopted. Levels at short distances entail a heavy cost. Mr. Darlington gives † the following statement of the extent of the levels driven in the Consolidated mines, Gwennap. In 1838 the adit had been extended to 1,678½ fathoms. Below this 32 levels were driven, 25 of them 10 fathoms, and 7 of them 5 fathoms apart. The winzes measured 13,631 fathoms, and the shafts 4,360 fathoms. The proportion, therefore, was 49 feet of *drivage* to 6 feet of shafts, and 15½ feet to 6 feet sunk in winzes. Had the levels been regularly driven 15 fathoms apart, it would have diminished the total horizontal length about one-third, and thus shortened the *drivages* by 11,883 fathoms, which valued at £5 10s. per fathom would involve a saving of £65,356, due exclusively to the extension of distances between the levels. By these remarks it is not intended to intimate that this large sum was lost by the proprietors, or that it would have been judicious to place all the levels 15 fathoms apart, but rather to invite the attention of mining agents to a consideration of this subject, and to convey to them an idea of the saving of expense, which under certain circumstances might be effected.

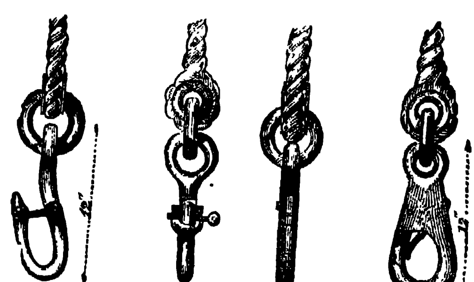

Fig. 162.

The annexed woodcuts, Fig. 162, show the characters of the hooks employed, which afford facilities for relieving the skip, and are so contrived as not to release it during its ascent or descent, as such an accident would prove fatal to the men below. Several schemes have been tried, but the two represented, where side and end views are shown, are found to answer most satisfactorily.

The left-hand hook is secured from unshipping by means of an iron pin passed through the return of the hook above a loop dropped over for the purpose; and the right-hand figure shows how similar security may be obtained, by a spring acting against a continuation of the hook, which is thus converted into a ring.

Subterraneous working.—The methods adopted in working a metalliferous mine must vary with the conditions under which the more valuable portions of the lode occur. It frequently happens that the rich ore is mixed, in the lode, with barren mineral matter, which is commonly called *veinstone.* In most cases it is necessary to break out all the deposits in the lode, but it is not always necessary that all should be taken to *grass*; con-

* Pryce, "Mineralogia Cornubiensis."

† "Records of Mining and Metallurgy." By John Arthur Phillips and John Darlington.

siderable quantities of the useless portions are thrown back to fill up the empty spaces, and special methods are required to properly meet the conditions as they occur. The valueless stones should be judiciously placed in the void left by the excavation, so as to form a good support for the unbroken rock.

The conditions of working small narrow lodes vary, in many respects, from those employed in mining broad ones. In either case a vertical shaft must be constructed, and by means of *cross cuts* at various depths the lode is reached. The intervals between the cross cuts vary from 8 fathoms to 12, or even, as before stated, in some cases to 15 fathoms. An inclined shaft is frequently used, especially in small and doubtful lodes, as it serves especially to explore the lode as it is sunk, but there are numerous advantages in a well-constructed vertical shaft. The cross cuts having reached the lode, the miners begin to drive galleries upon it, and if the exploration assures them of productiveness they begin regularly to work it away. The disposition of the richer parts of the lode will determine the condition and extent of the workings. The lode, if of fair average quality, will be divided into a series of galleries, at different levels. For the sake of ventilation and for bringing away the ore, a series of small shafts (*winzes*) are cut through, from one level to another; their distances from each other being uncertain, varying with the character of the lode from 15 fathoms to 30 fathoms. This is continued along the strike of the lode until the extremity of the *sett* (working area of the mine) or until the end of the richer portion of the lode is reached. To the depth — within the sett—there is no limit, except that of the cost of bringing the ore to the surface, which is constantly increasing with the depth. Levels are driven whenever the lode is intersected with a new cross cut, and winzes are cut through as the levels are lengthened. The annexed diagram, Fig. 163, of a portion of the Consolidated mines will, it is hoped, convey a correct idea of subterranean operations.*

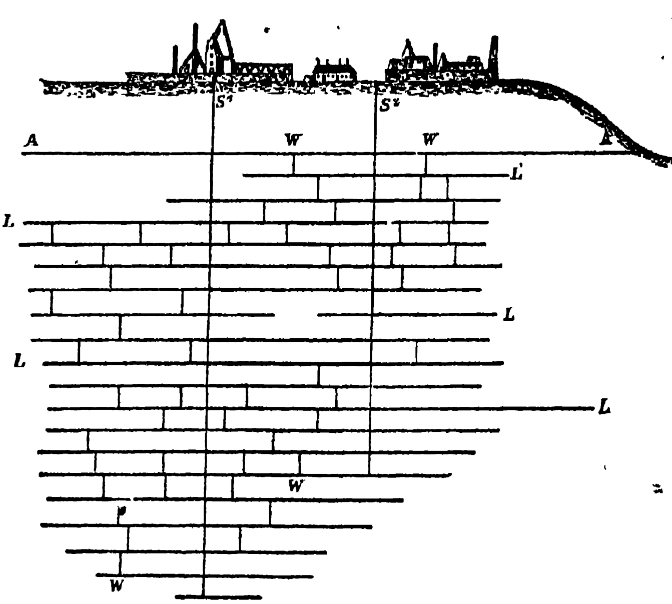

Fig. 163.—S^1 is the engine-shaft, usually called the *sump*-shaft. S^2 is a second shaft, which is mainly used for winding the ore to the surface. A A is the adit level, which intercepts much of the water percolating from above, and to which all the water from the lower parts of the mine is pumped through the engine-shaft, and discharged into the valley at A. L L indicates that all the horizontal lines are levels driven at uniform distances into and along the lode, by means of which the workings are carried on and the ore is removed. W W and all the short vertical lines connecting the levels, are winzes, by means of which the miners are enabled, by stoping, to break down the ore from the lode.

According to the richness of the lode, the winzes are, or should be, regulated, in order that the ore worked out in cutting them should pay the cost, or at least part of the cost, of sinking or rising. It will be evident by this that a metalliferous mine consists of a series of blocks or rectangular masses, each bounded by two levels, cut at intervals from the shaft S S, and by two winzes.

The work of the miner now consists in removing such blocks, or such portions of them, as are productive of metalliferous ores. A well laid-out mine will have a number of levels driven, and winzes cut, as the preliminary stages, so that a regular supply of ore may be obtained for months or for years, by removing the blocks one after the other. The "*ore in sight*" determines the commercial value of the mine, and it is only by opening upon the lode in this way that the quantity of ore in it can be determined. This is removed by *overhand stoping* and *underhand stoping*. *Overhand stopes* are formed by the removal of a block at its lower corner. A portion of the lode is broken down, perhaps to the height of 6 feet, thus raising the height of the level irregularly to that extent. The broken matter falls on the floor of the level, the metalliferous parts are picked out, and either allowed to accumulate or placed in barrows, or trams, for removal, and the rock without any mineral of value (*attle or deads*) is cast on one side, and placed on a wooden stage (*stull*) or on a stone arch, or used to fill exhausted spaces.

When the first stope has been advanced a fathom or more, a second is commenced, and the broken stuff falls into the level, to be treated as before. After a time a third stope is formed above the second, and thus is created a series of excavations, one above the other, parallel to the strike of the lode. Thus eventually we have a series of working places like steps, one a little behind the other. When a large space is formed by the excavations made by the processes described, the workings are carried on, as in any large subterranean working. (See Fig. 164.) The engraving shows the excavation going on in the second stope, and the work in an advanced state, exhibiting the construction of the leading lengths. The support required for carrying the upper stope and the tops may be obtained by props raking inwards, placed where they are not in the way. Where there is confidence in the stability of the square timbering of the level, a portion of the weight might be temporarily carried by propping. This mode of proceeding is best avoided, unless the circumstances of the case compel the miners to have recourse thereto. The rubbish is allowed to fall down, and thus it forms an irregular heap resting at the angle of repose, from which the term *overhand stopes* is derived. The broken ore from one stope falls on the rubbish of one below it, until it finally reaches the level, from which it is taken away in tram-waggons or in barrows.

Stopes are thus continued until they reach the winze on the other side of the block, and thus, at length, the whole of a block is removed. Usually a large portion of the lode is waste stuff (*deads* or *attle*), which should be carefully arranged so as to supply the place of the richer ore which has been taken away. The back of the lower level is well lined by a timber *stull*, or by a stone arch across the lode. One, or the other, carries the *deads*, and on these rests the floor of the upper level, the winzes being kept open by props and laths as already described.

Underhand stoping consists in *beginning* the work upon the block at one or other of its upper corners. The first *stope* is taken from the floor of the upper level to the depth of about 5 feet, and when this stope has advanced far enough a second stope is commenced. The deads, after the ore has been picked out, is thrown on to *stulls*, which are usually put up for every stope.

Underhand stoping is the reverse of *overhand stoping*. It is always advisable to maintain a few good roadways in the midst of the *deads* for conveying the mineral matter to the nearest winze, to be thrown into the lower level, or drawn by means of a windlass to the level above, from which it is sent to the shaft, through which it is to be drawn to the surface.

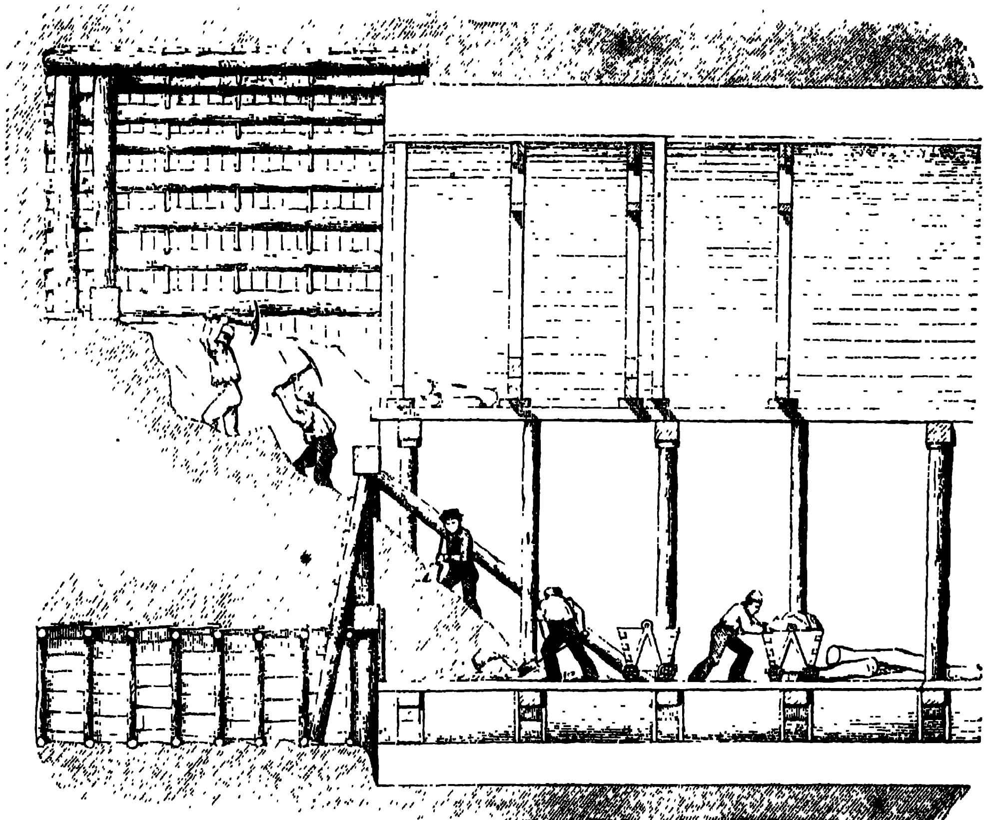

Fig. 164.

Sometimes these methods of stoping are carried on without a winze. *Overhand stopes* are begun by a *rise*, working away the lode upwards; and *underhand stopes* by a *sink*, working away the lode downwards. Each time that a portion has been risen or sunk, new works are begun both right and left.

Underhand stoping is frequently adopted in the German mines, and it is the usual practice in the mines of South America. It is rarely adopted in this country.

Sometimes small shafts are constructed at short intervals in the middle of the deads themselves. They are then built up with stones from the top of the level, and are continued gradually as the pile of rubbish increases in size.

The ore is generally allowed to fall directly into the level below, but sometimes a strong door is placed at the lower end of the shaft, and it is permitted to become full, and then the door being opened, the ore is arranged to fall at once into the waggons or barrows. It will be seen by this description that the working away of the ore is rendered easy by the system of working in *stopes* or steps, and the filling of the waste spaces is effected economically by using the material obtained on the spot where it is required. If it is thought to be advisable, a block or rectangular mass of ore can be speedily removed by placing a number of workmen to stope it at different places.

Economy, in general, points favourably to overhand stopes, since the quantity of timber used will only be that which is required for one long stope; but in the system of underhand stoping, stalls are required for nearly every stope in the block. The cost of the timber therefore regulates the system which should be adopted for working a mine.

Overhand stoping is most conveniently, and economically, employed when working in the wider parts of lodes, provided the rock is sufficiently coherent to allow the workings to be carried the whole width of the lode. By overhand stoping the lode is broken away with greater facility; the arrangements for stowing the valueless portions in the waste places are considerable, while the richer ore is sent into the levels and conveyed away with the least trouble. Beyond this, overhand stoping is generally regarded by the miner himself as the safest, especially where the walls of the lode are bad, and do not allow of the stulls being firmly fixed.

When the lode is much decomposed, and weak and friable, or when such a lode contains, as they often do, rich silver ores, or others equally valuable, underhand stoping is to be preferred. In the latter case—of rich ores—it must be remembered that by overhand stoping the ore falls on a floor made up of the deads of the understope, and the fragments of silver ore, especially the smaller ones, would be lost in the crevices between the stones of the rubbish. In underhand work the ore broken out falls on those parts of the lode which are still intact, and the miner has to remove this, and examine every piece as he does so, before he can proceed with his excavation. In a good-sized regular lode the chief levels should be on the foot-wall side, and connected so as to secure proper ventilation by winzes, one with the other. Cross cuts are now driven out of the main level, and carried on to the hanging wall, these being carefully timbered, and all waste spaces filled in with the refuse stones. By driving on the lode, portions of it are gradually worked away, and if it is thought advisable, several sections may thus be removed simultaneously.

In large lodes we often find many branches enclosing large masses (*horses*) of the same kind as the rock in which the lode occurs. Frequently the miner in cross-cutting meets with these *horses* before he reaches the upper wall of the lode. After an examination of each horse, if it is found to contain no ore, it is left standing, and the cross cuts are driven on to the upper wall of the lode, and two separate workings are established—on the *hanging wall* and on the *foot-wall* of the lode. When refuse matter cannot be obtained to fill up the spaces from which ore has been removed, it becomes imperative to obtain waste stuff from some other source, or if it cannot be

obtained without the cost of quarrying it, conveying it underground, and then training it to the place for which it is required, the supporting pillars may be removed and the roof allowed to fall in. This is a process which is always attended with some danger.

In cases where the lode is too wide, and the strength—the coherence of the contents—of the lode is not sufficient to support itself, a level is often driven in the middle of the ore, unless one of the walls offers sufficient security. The level being in the middle of the lode, the other parts are taken away by working from one side (*wall*) to the other, or by *cross-cutting*. The strength of the lode determines the width which can be given to those cuttings, and their direction is settled by a consideration of the line most suitable for working away the metallic ores. One set of cross cuts (commonly called *drivages*) having been finished, and then packed with the deads, another cut is worked, and another section of the vein removed, until at last all the ore has been taken away, and its place supplied with the rubbish cautiously stored. When these packings of the deads have stood for some time they settle down, and the pieces get cemented together by the water percolating through them, depositing either lime or oxide of iron, and the wall becomes as firm as any part of the lode itself. When consolidation has taken place, that portion of the lode which is immediately beneath the deads can be removed, leaving a small wall of support, at either end, for the deads to rest upon. Where the deads are not sufficiently solid, an arch of ground should be left, which may be eventually removed when all the other work is finished. It must never be forgotten that at all times channels must be preserved for the circulation of air, ventilation being essential to secure the health of the men. If the lode has proved rich and continuous in several levels, and stoping has been carried on in the most complete manner, the spaces between the levels will be vacant unless by judicious timbering or walling and packing of the rejected mass the cavities have all been filled, except where channels have been preserved for the purposes of ventilation. This is often neglected or incautiously carried out, and great waste is the consequence. Often, especially when the mine has been worked in stratified deposits, a subsidence of the superposed stratum will take place, disturbing all the arrangements which have previously been made.

The following remarks by Sir Henry de la Beche are so much to the purpose that they are quoted entire.*

"The open spaces whence ore has been taken vary considerably, as must happen according to the breadth of the lodes in those situations and the amount of ore in them, for the lode may be broad or big enough, and yet not contain ore in sufficient quantities to be worked. There can be scarcely any rule in a variable thing like a mineral vein or lode as to the breadth of the parts which may be worth working, for though small, with little ore in some places, it may be several feet across in others, and be there rich; or it may be thin and rich in one place and broad and comparatively poor in another, so that it may even be questionable how far it may be advisable to take that portion out at all. These are matters upon which the chief agents decide according to their skill and judgment. It is usual in mines, particu-

* "Report on the Geology of Cornwall, Devon, and West Somerset." By Henry T. de la Beche.

larly those worked on the large scale and for a continuance, not to take out all the ore which could be immediately got at if thought necessary, but to leave it here and there to be worked as the general prospects of the mine may require, and to which the miners return if less ore is raised generally in the adventure than could be wished. The ores thus left in various places are often termed the *eyes* of the mine, and when it may be necessary, in abandoning the mine, or from any pressing circumstances, to remove them, it is termed *picking out the eyes of the mine.* In some mines these '*eyes*' are very valuable, and much skill and judgment are employed by the captains in so arranging the workings that a general good supply of ores may be obtained."

Cases do occasionally arise where the lode does not furnish any deads for stowage, and the produce of the mine will not cover the cost of bringing stones for stowage from a distance. Then the advisable plan is to divide the lode into sections and drive levels at the bottom of each section, leaving a solid roof above. In mining in this manner the excavations in one division should correspond exactly with those above, and thus secure that the pillars left in the upper section rest on the solid pillars beneath. The quantity of ore that can be safely removed in this way depends on the nature of the rock or of the lode, and demands all the care and consideration which the agent can give to it. When the more valuable portions have been taken away, if it is thought desirable to obtain the other less valuable portion, the miner works away the innermost pillar, or standing mass, and eventually breaks through it, allowing the upper portion to fall. He then proceeds in the same way with the next, and so on until no more good ore is left, or it becomes too dangerous to attempt to obtain it. A neglect of attention to these points has sometimes led to a serious subsidence of the upper rocks, or parts of the lode, resulting in severe injury, or even death, the miner getting crushed beneath the falling mass, and considerable loss to the proprietor of the mine.

CHAPTER III.

VENTILATION OF MINES—DRAINAGE OF MINES, ETC.

Ventilation of Mines.—The ventilation of metalliferous mines is not surrounded with the difficulties and dangers which are always present in collieries. Explosions of the mixture of light carburetted hydrogen with atmospheric air, which are common in coal mines, are rarely heard of in metalliferous mines. The Van mine in North Wales is a singular example of the production of this gas from natural causes. At wide intervals of time a little explosive gas has been met with in the Cornish mines, and in the lead mines of other counties, especially when the lead lode has been worked near to, or in, the Coal Measures.

There are two or three causes existing in metallic mines which tend to render the air injurious to the miners. The burning of candles, the explosions of gunpowder, and the natural processes of respiration, each tend to deprive the air of some of its oxygen, and thus deteriorate it; and, by the processes of combustion and respiration, a considerable proportion of carbonic acid is constantly being added to the air. Sulphurous acid is given out by the burning of gunpowder, and nitrous acid, by the decomposition of the nitrate of potash, is also produced in small quantities.

Where the mines are worked in Limestone strata large quantities of carbonic acid are constantly being poured into the air from the rock itself. The difficulties of ventilating the workings in the close end of an adit have been already spoken of. The vitiated air of the close ends of levels is often so largely impregnated with this heavy gas, as to be unable to support combustion, and consequently insufficient for the healthful maintenance of vital power.

Under ordinary circumstances, when a mine is properly opened, a natural process of ventilation is established, depending on the temperature of rocks in which the excavations are made. A very simple experiment will prove that it is easy to establish an ascending and descending current of air. If a very tall glass jar is taken, and a lighted taper placed at the bottom of it, in a very short time so much of the oxygen will be consumed, or converted into carbonic acid, that the flame will be considerably diminished, and would in a short time be extinguished. If now a long piece of pasteboard be passed so as to reach nearly to the bottom of the jar, a down current of pure air will be established, while the warmed and vitiated air will steadily ascend and the flame burn brightly. Upon this principle depends the power of ventilating the deepest and most extensive mines.

It has been already stated that the temperature of the rocks increases,

in an uniform ratio. Mr. R. W. Fox established the fact that the temperature of our mines increases with the depth in a regularly diminishing ratio. The following table is based on the extensive observations of Mr. W. J. Henwood* :—

—	Surface to 50 Fathoms.		50 to 100 Fathoms.		100 to 150 Fathoms.		150 to 200 Fathoms.		200 Fathoms and beyond.		Mean.	
	Depth.	Temp.	Depth.	Temp.	Depth.	Temp.	Depth.	Temp.	Depth.	Temp.	Depth.	Temp.
	Fms.	Degrs.	Fms.	Degrs.	Fms.	Degrs.	Fms.	Degrs.	Fms.	Degrs.	Fms.	Degrs.
St. Just . .	25	51·45	70	50·17	128	62·75	156	61·01	—	—	95	57·84
St. Ives . .	28	54·16	73	59·64	119	67·0	197	63·01	228	72·0	129	63·56
Marazion .	33	58·62	64	61·66	131	71·33	—	—	—	—	76	63·87
Gwinnear. .	28	57·1	78	63·53	131	66·0	167	76·0	—	—	101	63·4
Helston . .	31	56·6	8[illegible]	62·1	133	66·1	190	68·5	237	80·0	134	66·66
Camborne .	21	53·3	78	61·5	125	66·54	168	67·17	—	—	98	62·13
Redruth . .	33	52·7	76	58·3	130	70·64	177	86·07	245	89·17	132	71·27
St. Agnes .	39	58·5	75	63·9	129	69·0	154	72·25	—	—	99	65·91
St. Austell .	—	—	52	55·0	111	71·0	160	67·75	220	88·76	136	70·62
Tavistock .	30	54·3	67	58·75	118	64·16	—	—	—	—	72	59·7
Mean . .	30	54·87	72	60·80	127	67·43	173	78·0	240	85·52	112	66·88

The mean temperature at nearly equal depths in Granite and Slate rock is given as follows :—

Depths.	Granite.		Slate.	
	Depth.	Temp.	Depth.	Temp.
	Fms.	Degrees.	Fms.	Degrees.
Surface to 50 fathoms	25	52·67	30	55·9
50 to 100 „	71	57·68	73	61·9
100 to 150 „	132	65·0	125	68·14
150 to 200 „	161	65·71	174	79·17
200 fathoms and beyond . .	240	76·15	241	89·4
Mean	94	68·35	116	68·89

The mean annual temperature, at the depth of three feet from the surface, has been determined by Mr. Fox† :—

	Degrees.
At Wheal Gorland (Granite)	48·09
At Dolcoath (Slate)	48·94
At Falmouth (Slate)	50·67
Mean	49·86

Mr. Henwood's experiments led him to concur with Mr. Fox in beginning his computations at 500 yards. The temperatures given in the above tables do not coincide in all cases, but the inequalities are so slight that we are justified in considering the mean of the surface temperature at

* W. J. Henwood, "On the Temperature of the Mines of Cornwall and Devon." ("Transactions of the Royal Geological Society of Cornwall," vol. v.)

† R. W. Fox, "Cornwall Geological Transactions."

50°. Numerous observations have been made both in this country, on the continent of Europe, and in America, in mines, and Artesian wells, hoping to determine the rate of increase in subterranean temperature. None of these are quite free from the suspicion of errors. In evidence given by the author before the Royal Coal Commission, the whole question has been examined, and to that the reader, who is interested in the question, is referred. For the purposes of the present consideration it is sufficient to know that there is a regular rate of increase, about 1° Fah. for every 50 feet of depth,—the ratio of increase being, to the depth which has been penetrated, a constantly diminishing one.

The most recent observations which have been made are those of Captain Josiah Thomas, of Dolcoath mine, the results of which were read before a meeting of the Mining Institute. The following portion of that communication is of such interest that it deserves to be quoted:—

"Mr. W. Jory Henwood, of Penzance, in a work published in 1871, gives the results of many hundreds of observations made in mines in every district of Cornwall, extending over a series of years. His general deductions from all the observations are, that Slate rocks are warmer than Granite, that rocks are warmer than lodes, and that copper lodes are warmer than those lodes that produce tin. His conclusions are that the increase of heat downwards to a depth of 240 fathoms was in Slate rocks 1° for every 38 feet, and in Granite 1° for every 55 feet in depth.

"In a work on Geology just published by Professor Archibald Geikie, Director of the Geological Survey of Great Britain, he states that 'according to present knowledge the average rate of increase amounts to 1° Fah. for every 50 or 60 feet of descent, and this rise is found whether the boring be made at the sea-level or on elevated ground.' Finally, Professor Everett has recently drawn up a summary of results of reports of underground temperature made for the British Association, from which it appears that the greatest increase of temperature was in 'shale' in a boring near Glasgow, 450 feet deep, where the ratio was 1° in 30 feet; and that the lowest rate of increase was in a mine in Bohemia in quartzose rock, 1,900 feet deep, where the ratio was 1° in 135 feet. The deepest mine in which experiments have been made was in Ashton Moss Colliery, near Manchester, which was at the time 2,790 feet or 465 fathoms deep; and in this mine the rate of increase was found to be 1° in 77 feet. The mean increase of temperature in all the experiments made in different parts of the world is said by Professor Everett to be 1° in 64 feet.

"I have of late been making some observations on the temperature of Dolcoath mine, the lower workings of which are in Granite, and I thought the results might be somewhat interesting, as I am not aware that any experiments have hitherto been made in Granite at so great a depth. Mr. Henwood's experiments were for the most part made in the *water* which issued from the rocks; but this scarcely seems to be the best method of obtaining the most accurate results, for it is well known that the temperature of water is affected by chemical action taking place in the lodes, as at Clifford Amalgamated mine, in Gwennap, where the temperature of the water was 116°. It must also be necessarily affected by the cold surface water passing down-

ward through the lodes and cross courses. In the observations that I have made, therefore, I have had holes bored two feet in dry rock, in which I have inserted one of Negretti and Zambra's slow-action mining thermometers. The thermometer, which is about 10 inches long, was put down to the bottom of the hole. The upper part of the hole was then plugged up with woollen material and covered on the outside with soft clay, so as to keep out all the atmosphere. The thermometer was left in the holes for various periods, varying from half an hour to a week. The results of the trials are as follows:—

Fathom Level.	Fathoms Perpendicular below Surface.	Temperature of Rock.	Temperature of Air.
At the 12	42	64 deg.	65 deg.
,, 40	65	65 ,,	66½ ,,
,, 125	146	67¾ ,,	68 ,,
,, 170	188	65 ,,	66 ,,
,, 302	314	70 ,,	71 ,,
,, 352	354	83 ,,	81 ,,

"In reference to the temperature of the rock at the 170-fathom level, which was lower than at the 125-fathom, it should be observed that a cold current of air had, for some time past, been passing through the 170-fathom, which no doubt diminished the heat of the rock, at least to a depth of some feet. The thermometer at the 12-fathom level was allowed to remain in the hole three days, and that in the 352-fathom level was in the hole seven days. The temperature of the rock at the 12-fathom level, 42 fathoms (perpendicular) below surface, was found to be 64°, and at the 352-fathom level (312 fathoms deeper) 83°, being an increase of 19°, or 1° in 98½ feet. I think that in taking these two extreme points we have a fair test of the real temperature of the rocks at Dolcoath, and the true rate of increase. The temperature in the intermediate levels may possibly be affected by currents of air passing through them, and by other causes; but the hole at the 352-fathom level was in clean Granite, about 15 fathoms inside any draught, and 4 fathoms behind the end, in new ground recently driven through, and therefore we may suppose that the temperature observed at this point was the natural heat of the rock.

"The results of my present observations are very different from those that had previously been made in Dolcoath mine, as recorded by various writers. Sir H. de la Beche says that from a report made to the British Association in 1837 the temperature in Dolcoath at 230 fathoms deep was about 75°; and that the heat increased 1° for every 51 feet. Mr. W. J. Henwood says that the temperature in 1822, at 230 fathoms deep, was 75½°, and that it increased 1° in 54 feet. He also says that in 1857, at a depth of 272 fathoms, the temperature was 73°, or 2½° less than in 1822, although the mine was 42 fathoms deeper, and that the rate of increase was 1° in 70 feet. I now find that the temperature at the 352-fathom level, 354 fathoms perpendicular from surface, is 83°, and that the rate of increase as before stated is 1° in 98½ feet. But although the actual results of various

observations, both in Cornwall and in other parts of the world, somewhat widely differ, yet it is a remarkable fact that everywhere, without a single exception, *the heat increases* as depth is attained, and nowhere has the temperature been found to be *less* in depth. Professor Archibald Geikie remarks that, 'Supposing the rise of temperature, as observed to the depth reached, continues at the same ratio, the temperature at 20 miles would be 1,700°, and at 50 miles deep 4,500°.'"

In connection with subterranean temperature, the important point with which we are more immediately concerned is that the heat does increase with the depth, and consequently that the air becomes warmer, and has a constantly increasing tendency to flow upwards. This may be illustrated by a very simple experiment. Connect two long glass tubes together by a U-shaped piece of metallic tube at the bottom. The temperature of the air in each tube being the same, it remains undisturbed, but the slightest application of heat—even the warmth of the hand—is sufficient to establish an upward flow in one tube, and consequently to produce a downward current in the other. On a large scale this is what takes place in the working of a mine by what has been called *natural ventilation.*

In 1813 an improved system of ventilation in our collieries was introduced by Mr. Buddle, of Newcastle-upon-Tyne, by providing several channels for the air, instead of passing it through a single course. It has been hitherto the usual practice to fix a furnace at the bottom of one shaft in collieries, so as to rarefy the air, by which it was made to ascend. This is called the "*upcast*" shaft. Consequently the colder external air, which is of greater weight, then descends another shaft, which is called the "*downcast*" shaft, and by well-devised arrangements the current of air is circulated through all the devious windings of a colliery. The furnace system of ventilation is rapidly passing out of use, mechanical ventilation having been proved to be much more economical and effective. Where the colliery has not two shafts—a state of things which is being discontinued—it has been the custom to obtain the same result by dividing the single shaft by a *brattice*, which may be either of prepared cloth or a division of thin boarding. In either case it is not difficult to produce an upward flow of air from the depth of the pit, and consequently to establish a downward current of fresh atmospheric air. A committee of the North of England Institute of Mining Engineers recently made some investigations as to the efficiency of different kinds of mechanical ventilators. These experiments bore directly on the ventilation of collieries, but with the increasing depths of our metalliferous mines, and the rapid extension of the workings, it will become an imperative necessity to adopt, to a greater or a less extent, similar mechanical appliances in them to those which have been found to be so useful in our collieries.*

With this idea, it is considered important to place in the hands of the metalliferous miner a table of the efficiencies of mechanical ventilators, compiled from the report, by Mr. Henry Davey, of Leeds †:—

* See "Transactions of the North of England Institute of Mining Engineers," vol. xxx., 1880–81, pp. 288–290.

† "Mining Machinery." By Henry Davey. (Excerpt Minutes of Proceedings of the Meeting of the Mechanical Engineers in Leeds, 16th August, 1882.)

EFFICIENCIES OF MECHANICAL VENTILATORS.

No.	Name of Ventilating Machines.	Dimensions of Ventilating Machines.					Dimensions of Engines.				General Remarks.		
		Diameter.	Width, &c.	Theoretical Displacement per Minute.	Diameter of Inlet.	Weight	No. of Cyls.	Dia. of Cyls.	Length of Stroke.	Direct-acting or geared.	Volume of Air per Minute.	Mean Water Gauge at Drift Door.	Percentage of Useful Effect.
		Ft. in.	Ft. in.	Cub. ft.	Ft. in.	Tons.	No.	In.	Ft. in.		Cub. ft.	Inches.	Per cent.
1	Guibal .	Fan 50 0	12 0	—	15 0	50	1	42	3 6	Direct	108,422	3·30	40·00
2	Do. .	„ 46 0	14 10	—	13 0	—	1	36	3 6	Direct	246,509	1·85	52·95
3	Do. .	„ 40 0	12 0	—	14 0	24	1	36	3 0	Direct	170,581	1·46	47·95
4	Waddle .	„ 45 0	Inlet 6 6 Periphery 1 5	—	15 0	—	1	32	4 0	Direct	163,312	3·08	52·79
5	Schiele .	„ 12 0	2 1	—	—	—	1	25	2 0	2·57 to 1	157,176	1·91	46·12
6	Do. .	„ 9 6	Inlet 3 2 Periphery 1 8	—	8 0	—	1	20	1 8	$2\frac{1}{2}$ to 1	106,570	2·03	49·27
7	*Lemielle	Chamber 22 6 Drum 15 0	Height 32 0	9·9 rev. 108,900	—	—	1	55	6 0	Direct	47,307	1·37	23·40
8	Struvé .	2 Pistons 18 3	Stroke 7 0	$6\frac{1}{2}$ rev. 47,827	—	—	1	24	4 $4\frac{1}{2}$	4 to 1	43,793	5·11	57·80
9	Nixon .	2 Pistons, 30 ft. long, 20 ft. high	Stroke 7 0	7·19 rev. 120,790	—	—	1	36	6 0	Direct	72,595	2·74	45·91
10	Root .	2 Drums 25 0	13 0	16·71 rev. 96,918	—	—	2	28	4 0	Direct	89,772	3·29	47·84
11	Cooke .	2 Drums 15 0 Casing 22 0	11 6	17·92 rev. 80,640	—	—	1	25	3 6	Direct	54,190	1·12	37·33
12	Goffint .	2 Pistons 13 2	Stroke 10 $7\frac{1}{4}$	$9\frac{1}{4}$ rev. 53,020	—	—	2	$15\frac{3}{4}$	10 $7\frac{3}{4}$	Direct	36,286	0·71	25·79

In 1764, Jars, in his "Voyages Métallurgiques," laid down the principles of mechanical ventilation; and Mr. Spedding, in 1760, greatly improved this system in the North of England. In mines where no mechanical appliances are employed for ventilating the workings, precautions should be taken to keep the levels well open, and to prevent any leakage of air into old workings. Care should be also taken to convey the air from one level to another, and to all the various working places. This is of course effected by placing properly-constructed stops in certain places, so as to produce a current, regularly flowing in one direction. It has been considered a good rule never to allow the velocity with which the air traverses the levels to exceed 5 feet per second, or to fall short of 6 inches per second. Bellows and fans of various descriptions have been employed for ventilating purposes. The bellows employed have usually been of the compound character, emitting a continuous blast of air. Fans of various descriptions have been employed with different degrees of advantage. M. Ponson has given the following table, from which may be gathered the actual value of several of the ventilating fans:—

Names of the Ventilators.	Maximum of Bulk Extract.	Correspondent Depression.	Useful Power in Horses.	Depression Maximum.	Correspondent Bulk of Air Extract.	Useful Power in Horses.
	Cub. yd.				Cub. yd.	
With Curved Wings (Combs)	6·08	0·″826	1·27	1·″495	3·70	1·44
With Plane Wings (or centri fugal force) . . .	9·24	1·″968	4·61	2·″282	1·304	0·76
With Screw (Notte) . .	8·61	0·″826	1·80	0·″983	5·640	1·40
With Spiral (Paquet) .	13·83	1·″101	3·87	1·″770	8·000	3·60
With Mill Wings (Lesoigne)	12·16	0·″511	1·98	0·″511	12·160	1·98
With Wheel (Fabry) .	16·84	1·″613	6·96	3·″385	5·600	4·82

It is seen by this table that the maximum of the dislodged air is somewhat inferior to 17·32 cubic yards, and that the maximum of the depression obtained is 3·″385. Now, as the latter indicates precisely the measure of the ventilating power of the apparatus, the most perfect will be the one which can reach a great depression, and at the same time dispose of a considerable amount of air. None of those mentioned in the above table performs these conditions, for in all of them does the volume of the dislodged air decrease, with excessive rapidity, in proportion to the increase of depression. The maximum of the one corresponds with the minimum of the other.

It is clear, then, that at a point very close to the maximum of the depression indicated above, these machines must work without producing any effect, as the air entering almost equals the amount of the dislodged air.

M. Lemielle's ventilator with pneumatic wings has been extensively used. It extracts on an average 16 cubic yards of air per second, and its distinguishing feature is that it possesses the advantage of dislodging that volume of air under considerable depression.

The following table was constructed—by M. Le Verrier, Engineer to the Imperial Administration of Mines at Lille—to show the results of experiments made in a mine near Douai:—

Number of Turnings of the Ventilator per Minute.	Volume of Air extracted from the Mine per Second.	Depression. Maximum.	Velocity of the Air per Second in the Gallery which conducts to the Ventilator. (27 square feet, 24 section.)	Useful Power in Horses.	Volume of Air extracted by each Revolution of the Ventilator.
	Cubic yards.		Yards.		Cubic yards.
10	8·00	2·"731	3·20	3·52	48
17	14·00	4·"133	5·60	14·70	49·51
21	16·87	5·"511	6·88	23·61	49·32
26	21·53	6·"299	8·33	34·44	49·68

The obstacles to the motion of air in the levels of a mine are in direct proportion to their length—to the perimeter of their section—to the square of the velocity of the current—and in inverse proportion to the area of the section. The longer the passages, the narrower the galleries are, and the more rapid the current, the more considerable will be the depression. The miner should, therefore, give the preference to a ventilator which will produce the most powerful depression. M. Lemielle offers to furnish the miner with apparatus capable of extracting air from the works, and with the necessary depression from 40 cubic yards to 133 cubic yards per second.

Screws of various kinds have been employed in small pieces of apparatus for sending air into close ends. The Archimedean screw has been employed for this purpose with considerable advantage. The *duck machine*, as it has been called, consisting of two inverted tubs working up and down in vessels of water, acting by exhaustion, was first introduced by the late Mr. John Taylor, and it was employed by him when constructing the tunnel at Tavistock. The same principle has been patented by Mr. Struvé, of Swansea, and applied with much success in some of the collieries of South Wales. Mr. Low, of Loft Wen, near Wrexham, invented an apparatus composed of a series of small tubes fixed vertically around the pit at any convenient depth, and heated by steam drawn from the engine boiler. The introduction of steam heats the tubes to about 212° Fah., and the radiation of heat from their outer surface causes a considerable rarefaction of the air in the shaft, and thus ventilates the mine.

Mr. W. Teague, of Tincroft mine, Cornwall, has introduced a ventilator the principle of which will be at once understood by the annexed sketch.

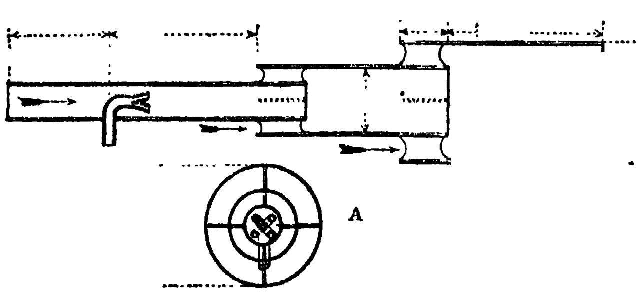

Fig. 165.

Fig. 165 is an air, or steam, ventilator. A trial of it has been made at Carn Brea mine, Cornwall, on which occasion over 8,000 cubic feet of air were passed through the machine in one minute. This was accomplished by a 1-inch pipe with four jets, supplied with a pressure of air to the extent of 60 lbs. to the square inch, passing through a 4-inch pipe with two outer rings, A. These outer rings produced a powerful exhaustion. At the same time the

principal inlet was not lessened, but was maintained throughout, and gathers in force in proportion to the additional rings attached. The velocity of the air was at the rate of 728 feet per minute. Thus it is said to be possible, if an adequate number of these machines are brought into requisition, to pass upwards of 3,000,000 cubic feet of air through the mouth of a 20-feet shaft in one minute.

Fig. 166 is a compressed-air ventilator adapted to tunnel headings, &c. It is being worked successfully in the Cornish mines. With this single machine, supplied with a 1-inch pipe and four jets with 60 lbs. pressure, the largest blast in a 7-feet heading can be cleared in less than ten minutes. Where the utmost speed is required, the smoke may be cleared instantaneously by having two or more machines. The great advantage is that no delay is experienced after the blasting, the men are enabled to resume work immediately in an atmosphere freed of noxious gases: thus good ventilation can be effected at any distance.

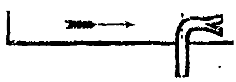

Fig. 166.

It will be evident that this ventilator involves an application of the principles to which the late Sir Goldworthy Gurney first drew attention. Gurney's "*Steam Jet*" was on some occasions used with much advantage in collieries, especially for removing the products of combustion, and freeing a colliery from the "*after damp.*" For ventilation it was used under several conditions. Mr. W. Teague's application possesses great merit and promises many considerable advantages, especially from the rapidity with which it clears close ends of the deleterious gases produced by the explosion of gunpowder, of nitro-glycerine, of dynamite, or of any of the other explosive compounds which have been recently introduced.

The *Anemometer* represented in the woodcut, Fig. 167, a useful instrument for determining the rate at which the air travels through the working of a mine, is of the pattern usually known as Biram's—that celebrated colliery viewer having introduced the instrument into the Earl of Fitzwilliam's collieries in Yorkshire. It consists essentially of six vanes, made of thin sheet brass; these are delicately mounted on a centre moving freely within a brass ring. It is carried by the handle, and indicates the most gentle current, the rate at which the vanes revolve being noted by the index shown in the centre of the figure.

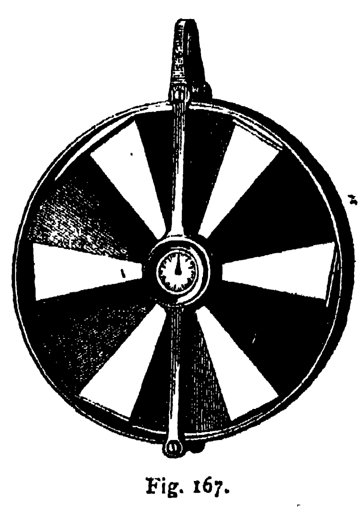

Fig. 167.

Immediately connected with the question of the ventilation of metalliferous mines, there arises the important one of freeing the workings from the deleterious gases produced by the explosive compounds used in blasting the rocks underground. The following list has been furnished by the "Explosives Committee," appointed

by the three Cornish societies * which give their especial attention to the improvement of mining:—

A. GUNPOWDER.—Large grain (1), medium grain (2), small grain (3), compressed (4):—

Charcoal	15 per cent.	approximately.
Sulphur	15 „	
Nitre	70 „	

A. GUNPOWDER.—Special strong (5). Composition not stated.

B. ESPIR'S EXPLOSIVE POWDER:—

Nitrate of Soda	60 per cent.	approximately.
Sulphur	14 „	
Hardwood Sawdust	26 „	

C. GUN-COTTON.—Pure cotton fibre which has been chemically acted on by strong acids.

D. TONITE.—Said to be gun-cotton, combined with nitrate of baryta.

E. TITANITE.—No information.

F. DYNAMITE:—

No. 1. Nitro-glycerine	75 per cent.	approximately.
Kieselguhr†	25 „	

No. 2. Contains less nitro-glycerine, together with varying proportions of charcoal and a nitrate.

G. No. 2. BLASTING GELATINE.—"Collodion cotton 7 to 10 parts, combined with thoroughly purified nitro-glycerine 90 to 93 parts, at least 95 per cent. of the collodion cotton to be soluble in ether and alcohol."

H. LIVERPOOL COTTON POWDER.—Said to be gun-cotton combined with nitrate of potash.

I. PUDROLYTHE.

In answer to a number of questions circulated amongst the miners as to the relative cost of these explosives, for doing an equal amount of work under different conditions, the following replies were received:—

A. In wet ground	31 replies; Dynamite best 26, coarse Powder best 3, Tonite best 2.
B. In very dry ground	23 replies; Dynamite best 3, Powder best 10, fine Powder best 2, large Powder best 2, medium Powder best 2, compressed Powder best 2, Tonite best 2.
C. In loose or fissured ground	23 replies; Dynamite best 18, Powder best 2, Tonite best 2, large Powder best 1.
D. In ends	29 replies; Dynamite best 13, Powder best 9, Tonite best 2, Dynamite if wet or hard, Powder if dry or moderate 5.
E. In back stopes	18 replies; Dynamite best 7, Powder best 5, medium Powder best 1, small Powder best 1, compressed Powder best 1, Dynamite if wet or hard, Powder if dry or moderate 3.
F. In sinking	23 replies; Dynamite best 14, Powder best 3, large Powder best 2, small Powder best 1, Dynamite if wet or hard, Powder if dry or moderate 3.
G. In open quarry work	13 replies; Powder best 8, large Powder best 1, Dynamite best 2, Pudrolythe best 1, Dynamite where small stones are required 1. One reply said Dynamite is best under *all* circumstances.

Another question related to the relative safety or danger in using these different explosives. The replies to this query were very conflicting; the majority considered dynamite to be safer in use than powder, but that it required more care *after* use, *i.e.* in working the rock after it has been used. One reply states, that the writer had used 2 tons of dynamite per annum, for many years, without accident. Capt. Henry Eddy, of North Levant mine, answers this question as follows: "Dynamite extremely dangerous. Lithofracteur highly dangerous. Powder moderately dangerous." Captains Jas. Vigus and Wm. Gribble say: "Tonite safest, dynamite next, Espir's powder next, then gunpowder."

The opinions of the miners being requested, as to the effects of the fumes or the smoke upon the men after a shot underground, we find that all except two agree that the fumes from dynamite are the most injurious. One of

* The Royal Cornwall Polytechnic Society, the Miners' Association of Cornwall and Devon, the Mining Institute of Cornwall.

† Infusorial earth consisting of the silicious skeletons of microscopic organisms.

these, Capt. Abraham James, of South Frances mine, says: "The fumes from dynamite are comparatively little when compared with powder, and with ordinary caution men need not suffer much from dynamite. I believe powder smoke in close places to be far more injurious." Capt. R. H. Williams, of Wheal Eliza, says: "We do not find dynamite injurious in ventilated places. We find the resultant gases from blasting with it much thinner and lighter than powder-smoke. We use dynamite almost exclusively—not from compulsion—but from the choice of men and agents." Most of the miners say that the fumes from powder are the least injurious, but one says they are the worst. Other explosives are believed to be intermediate in this respect.

Capt. Abraham James (of South Frances) says: "In this mine we use nothing but dynamite, not because we think it more economical than powder, but simply for want of good ventilation. The mine will be thoroughly ventilated in a few days, we shall then insist on the men using powder in many places where dynamite is used now. We consider we pay equally as much now for drivage, as when no other explosive was used than powder. The workmen prefer dynamite because, in the first place, it is a little stronger, it requires no tamping, makes less smoke. It is a boon to the workmen, but little or no profit to the adventurer. In my opinion powder for ordinary ground is by far the cheapest explosive."

Sir Geo. M. Denys, Bart., of Richmond, Yorkshire, writes: "We have of course tried various kinds of gun-cotton, powder, and tonite, but prefer No. 2 dynamite to anything else, and use it almost entirely. In wet ground it is invaluable, it requires no tamping. It is safer than powder or cotton. In favourable places in roof or sole we can bore with a machine to a depth of 6 or 8 feet, and charge accordingly, bringing enormous burdens. In orey places, if not cautiously used, it smashes the rock, I think, overmuch."

Mr. Hort Huxham, M.I.C.E., writes: "For breaking up large masses of cast-iron, 'horses' from the bottoms of the iron-smelting furnaces, and such-like refractory material, gunpowder is practically *non-effective*, and the desired effect can only be obtained with dynamite or nitro-glycerine. For penetrating the very hard silicious 'Pennant' Sandstones and other hard rocks of this district, especially when heavily watered, the greatest economy and efficiency is arrived at when using a quick powerful explosive, such as dynamite, *with bore-holes of small diameter*. For dealing with moderately hard rocks and strong ground, other conditions, such as quantity of water, thickness and inclination of the beds, fissures and joints, size of pit or heading, ventilation, &c., would govern the economical and effective use of the explosive. For shales and other soft ground the slower-acting explosives, gunpowder—used with bore-holes of larger diameter—are much superior to dynamite in effectiveness and economy, and for even the hardest coal the latter explosive is useless. Practically, only gunpowder and dynamite are used in this (South Wales) district."

Mr. A. L. Stephenson, of Durham, says: "My opinion is that gunpowder when used with safety-fuse, and supplied to the men in small cases or in cartridges, is the safest, but if carelessly used, or carried loose, or in bags as was frequently the case some years ago), I think it more liable to

accident than dynamite. If gunpowder be used in the form of a cartridge, with safety-fuse attached, and carefully rammed with a copper rammer, with dry clay or other like material, free from grit, there is, I believe, no safer explosive in the market. Dynamite, on the contrary, should be used without tamping of any description, other than water or fine dry sand, poured in loosely, so as to avoid the danger of concussion from tamping with a rammer.

"In regard to boring holes after the use of dynamite, I heard of a case where, in boring a fresh hole, an explosion took place with fatal results, upon the boring chisel striking into a slight fissure in the Limestone rock, at a depth of 2 feet, into which it is supposed some nitro-glycerine from dynamite must have percolated from another hole that had been charged in its vicinity.

"The fumes of gunpowder are very readily dealt with by the ordinary means of underground ventilation, and in no case have I ever seen or heard of the densest fumes seriously affecting the men, but if the air is allowed to be constantly loaded with them, and no sufficient ventilating current established, then the constant inhalation prejudicially affects the men.

"When dynamite is properly exploded, the amount of noxious gases given off is small, and by waiting a very short time the slight fumes are carried off by the ventilating current. If, however, dynamite is *not* thoroughly exploded, and partly or wholly *burnt* away, the resulting nitrous gases are considerable in volume, and highly dangerous for the men to breathe. Fatal results have from time to time arisen from this cause, by the men returning before the fumes have cleared. In any unventilated pit or drift, or other confined working place, I should consider it dangerous for the men to return after an explosion of dynamite, without allowing a considerable time to elapse."

These, the results obtained by practical miners from the actual use of the various explosives named, are exceedingly valuable.

UNWATERING MINES.—In the drainage of mines the system of adits is one requiring much attention. Although the great Gwennap adit, as it is termed, through which the waters of numerous mines in Gwennap and near Redruth are discharged, has been noticed, some additional particulars appear necessary. It is, according to Mr. Thomas (who has carefully laid it down in his map of the mining district from Chacewater to Camborne), about 26,000 fathoms, or nearly 30 miles in length, the various branches being included. "The greatest length to which any branch appears to have been extended from the adit mouth is at Carclew mine, measuring about 4,800 fathoms, nearly 5½ miles. The highest ground it has penetrated is at Wheal Hope, where the adit is 70 fathoms deep at Chilcot's shaft, and is deeper in the branches extending from thence." This adit is 39 feet above the level of the sea at high water in Restronguet Creek, into which the waters discharged from it flow, its mouth being near Nangiles, in a valley communicating with the creek. The variable heights of other adits above the sea-level in the same district are given in the following table, also by Mr. Thomas. These form, in fact, the drainage system of one of the most important mining districts in the United Kingdom :—

Carn Marth Cove Water-shoot.	413 feet.
Adit at Laity Mill	52 "
New Wheal Virgin Adit	374 "

Peden-andrea, Redruth	287 feet.
Tresavean	208 „
Wheal Harmony	171 „
Wheal Mary	81 „
Wheal Sparnon, Redruth	315 „

It becomes necessary in this place to examine the subject of the accumulating of water in the mines. It is important to arrive at some general knowledge of the quantity of water which is found in mines, and which has to be pumped out of them. The only way of ascertaining this is, in the first place to determine the quantity of rain falling on the surface, to ascertain how much permeates the upper stratum, and the depth to which it penetrates.

Dr. Dalton instituted in 1796–98 some observations on the proportion of rain which penetrated to a depth of 3 feet in the earth. This absorbing surface was 10 inches in diameter; for the first year it was bare, but covered with grass for the last two years. The mean annual fall of rain was 33·55 inches, of which there penetrated to a depth of 3 feet, 8·41 inches. This gives the rain falling on an acre as 121,484 cubic feet a year, of which the absorption was 30,492 cubic feet, or an average daily absorption of 83 cubic feet per acre, the quantity absorbed being about a fourth part of the rain falling.* This of course represents the conditions prevailing at Manchester. We are more especially concerned with the rain which falls on the surface in our mining districts.

Mr. Thomas † estimated the drainage of the Fowey River in 1825 at about 160 feet per day from each acre of the country immediately upon its banks. In 1826 it was only 75 cubic feet per day from each acre. He considers the mean annual drainage to be about 43,800 cubic feet per acre, or 120 cubic feet per day.

Mr. Davies Gilbert gives, from observations carried on over six years, a mean of rainfall of 46 inches per annum, or 166,834 cubic feet per acre. Mr. W. J. Henwood and others compute, "supposing all that is taken up by the Earth flows out again in springs, the absorption by the surface will be the 0·26 part, or about a quarter of the whole rain falling during the year." Mr. Henwood carefully examined the Gwennap district, and determined the quantity of water falling in rain, and issuing from the rocks and veins, at various depths. The district examined includes all the mines which empty their waters into the great Gwennap adit, the various ramifications of which extend between 30 and 40 miles on nearly the same plane, and its extreme limits are about 5½ miles from its mouth. In some parts of its course it is not more than 12 or 15 fathoms deep, whilst in the more elevated grounds to which the adit penetrates, it is 70 fathoms below the surface. Throughout the district the average depth is probably from 35 to 45 fathoms.

Nine-tenths of this adit are excavated in Slate, the remainder being in Granite, and in many cases it passes through *Elvan courses*. It intersects almost every lode and cross vein in the Gwennap district. Mr. Henwood limited his inquiry to the quantity of water flowing through the *adit*, and derived from the various rocks, *lodes*, and *cross veins*, which it intersects,

* "Memoirs of the Manchester Society," vol. v.

† "History of Falmouth," p. 50. Tratham: Falmouth.

and to that drawn from greater depths and discharged into it by the steam-engines on the mines which it unwaters. Mr. Henwood says: "I have calculated the quantity of water thus intercepted, and raised, which flowed through the adit, and estimating that each bushel (84 lbs.) of coal consumed by the steam-engines will raise 50,000,000 lbs. of water 1 foot high (about the average duty of Cornish pumping-engines at the time the observations were made), the additional steam power which would be necessary to raise the whole of the water to the surface would require an annual increase of nearly 24,000 tons. The adit, therefore, effects a saving of about £19,000 a year in the mines which it unwaters for fuel alone."

The following table was constructed by this indefatigable observer from the following sources:—

1. "The Returns of Rainfall," published by the Royal Institution of Cornwall.
2. Mr. Daniell's Tables, published in the "Meteorological Essays."
3. Mr. Thomas's Observations on Carnon Stream, from his "History of Falmouth."
4. Lean's "Engine Reports."
5. "Meteorological Report of the Royal Institution of Cornwall."

Date.	Rain. Cubic Feet per Minute.	Surface Water. Cubic Feet per Minute.	Evaporation. Cubic Feet per Minute.	Water Discharged by Great Adit. Cubic Feet per Minute.	Water Drawn from a Depth of 190 to 200 fathoms Cubic Feet per Minute
1839.					
January	1354·	40·	180·	1460·	881·†
February	1559·	—	119·	—	—
March	1711·	—	134·	1675·	979·
April	1365·	—	357·	—	—
May	1245·	—	552·	—	—
June	1958·	—	506·	—	—
July	2382·	—	662·	1022·	850·
August	1072·	—	610·	885·	831·
September	2551·	—	328·*	1177·	709·
October	1570·	—	166·*	—	—
November	3346·	—	56·*	1064·	930·
December	3955·	—	42·*	1978·	946·
1840.					
January	2545·	—	104·	{ 2898· 1933· }	1119·‡
February	1786·	—	119·	—	—
March	92·	—	295·	{ 2149· 1994· }	1145·§
April	352·	—	283·	1174·	1021·
Mean of Year 1839	2005·	40·	309·	1323·	875·
From April, 1839, to May, 1840	1904·	—	310·	1627·	944·
Mean	1954·	40·	310·	1475·	909·

* Interpolated from the temperatures of these months in 1839, and the differences between the wet and dry bulb thermometers for corresponding months in 1840.

† This observation was made on the morning of the 1st January, and as the water flowing had been pumped out of the mines in the preceding month, the quantity is from Messrs. Lean's December report.

‡ These observations were made on the 1st and 27th January, and this amount is a mean of Messrs. Lean's quantities for December and January.

§ These experiments were made on the 9th and 27th of March; this result is therefore from Messrs. Lean's March report.

The foregoing table shows that the quantity of rain which fell on this track, during the period of inquiry, exceeded by about 0·66 part the united sums of the evaporation and streams flowing from the surface and adit. The rain is, therefore, fully adequate to the supply of all the springs in the district, whether their waters issue at the surface, or underground in the mines.

It has been pre-supposed that the Earth was in the same state of humidity at the beginning and end of the inquiries, but, as the rain requires some time to descend into the mines, the water pumped out of them cannot have been the same as fell at the time.

The average fall of rain during the period under consideration was	51·12 inches.		
The average annual evaporation	8·1	,,	or 15·83 per cent
The average annual water flowing from the surface	1·04	,,	or 2·03 ,,
The average annual water discharged by the adit	38·58	,,	or 75·42 ,,
The difference, unaccounted for	3·4	,,	or 6·65 ,,
	51·12		100

The following table, giving the rain for 1882 in Cornwall and the Scilly Islands, is a necessary appendage to the statements given, as it shows the rainfall of this recent period, and does not differ much from the remoter one.

	Rain in Inches.		Number of Rainy Days
Bodmin .	62·03	..	243
Truro .	48·10	..	224
Falmouth	60·25	..	247
Helston .	49·77	..	256
Scilly .	39·10	..	289
Means .	51·85		241

THE MEAN MONTHLY AND ANNUAL FALL OF RAIN IN CORNWALL FOR FIFTEEN YEARS—1866 TO 1880.

Month.	Penzance.	St. Austell.	New-Quay.	Liskeard.	Saltash.	Bodmin.	Launceston.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
January . . .	+5·78	6·08	4·29	+6·41	+6·99	+6·45	+7·92
February . .	4·10	4·26	3·25	4·54	4·84	4·72	5·96
March . .	3·06	3·22	2·51	3·47	3·43	3·35	4·14
April . .	2·79	3·16	2·12	3·39	3·50	3·19	3·76
May . .	2·15	2·84	−1·99	3·00	−2·88	2·99	3·29
June . .	−2·03	−2·78	2·04	−2·69	2·95	−2·61	−2·87
July . .	2·67	3·07	2·38	3·57	3·75	3·21	3·99
August . .	3·18	3·91	2·99	4·29	4·04	4·15	5·16
September . .	3·83	4·90	3·92	5·65	5·44	5·24	6·27
October . . .	5·12	5·30	4·16	5·84	5·49	6·05	7·35
November . .	4·93	5·00	3·64	4·76	4·84	5·06	5·82
December . .	5·42	+5·38	+4·35	5·66	5·72	5·73	7·15
Total . .	45·06	49·90	37·64	52·27	58·87	52·75	63·68

Sixteen values obtained by Mr. G. J. Symons give the mean at 49 inches. There is but little doubt the 50 inches represent the average of the whole county of Cornwall, which is twice the fall of rain in the Metropolis.

The proportion absorbed by the surface and penetrating to a mean depth of at least 35 fathoms (a very considerable part of it to much greater

depths) is 75 per cent. The rate at which rain water penetrates into the mines has been carefully investigated by Mr. W. J. Henwood. The results obtained by him show that when the surface waters have been carefully intercepted, by filling up pools, and plastering them with a tenacious clay, and by constructing small channels to aid the general drainage, the mines have been worked to a much greater depth with less powerful and less costly engines. It has been shown, by ascertaining the quantity of rain which has fallen, and of the water pumped from the mines, that the ratio of rain has been 18·19; and the means of thirteen mines, on which observations have been made for seven years, 13·95, which sums bear to each other the proportion of 0·766 to unity.

"Although in many mines most of the water finds its way to the deepest level, yet the shallower levels, as they are worked for a longer time, and usually extend further than the deep ones, often intercept a considerable quantity. To avoid as much as possible the heavy cost of pumping from great depths, the water in the shallower levels is at once conducted to the pumps. On this account the upper *lifts* of the pumps are almost, without exception, longer than the lower ones. But it may be presumed that the water thus naturally collected at each series (*lifts*) of pumps does not always, or indeed commonly, supply neither more nor less than the exact quantity required to fill the pumps. Whilst the water is in excess at one *level*, and for its drainage the pump should be worked rapidly, at others it is often insufficient. When there is such a deficiency, an artificial supply is allowed to descend to keep the pumps always filled (*solid*) lest the buckets, valves (*clacks*), &c., should be injured by the irregular action of the engine and other apparatus (*going into fork*)" (*Henwood*).

The same authority remarks: "If a perpendicular shaft were sunk in a rock perfectly homogeneous and destitute of lamination, joints, or veins, the portion drained by it would be an inverted cone, of which the bottom of the shaft would be the apex and the surface of the Earth the base. The diameter of this base would depend on the facility which the rock afforded for the descent of water. The dimensions of this cone would vary with the depth of the shaft, and consequently, if the water were solely derived from that surface, there would be a very simple relation between that depth and the quantity of water collected."

Mr. Thomas, in his report, remarks that the western part of Wheal Friendship is often drained to more than 40 fathoms under the adit, whilst the United mines, at a distance of about 600 fathoms, are worked at 160 fathoms below the adit, on the same lodes. "Hence it appears that the surface of the water circulating through these lodes has an inclination of about 12 degrees. If this should be taken as an average inclination in a dry season, where water circulates without interruption through the lodes, it shows that for every fathom in depth, the lodes will be drained to the distance of five fathoms at the surface, and the quantity of water at the same lode will increase in proportion to the square of the depth. In the *wet* season the inclination of the water line will of course be greater, from the quantity of moisture constantly supplying the Earth."

It has been conclusively determined that there exists a close relation

between the water in the mines and that pumped from them, and the quantity of rain which has fallen in the district in which they are situated. The intervals between the *maxima* and *minima* in the different mines are not the same. The column of rain always shows the proportion which fell just as many months before as would be required for its descent; which rain, therefore, must be considered the same water which is afterwards pumped out of the mines. In nature, the conditions to be investigated are complicated. Our rocks are often schistose; the structure of even the most regular is far from uniform; whilst all of them are traversed by joints and veins, and the mineral composition is liable to some variation at almost every fathom. Some of these circumstances impede the drainage whilst others facilitate it at almost incredible distances.*

Messrs. Lean have given a table † from which we obtain a very correct idea of the proportionate quantities of water pumped from the mines in different rocks. They state the *maxima* and *minima* quantities in cubic feet per minute, from forty mines during five years as follows:—

Years.	Maxima.		Minima.	
	Granite.	Slate.	Granite.	Slate.
1833	36·	164·	19·	89·
1834	35·	140·	15·	60·
1835	24·	88·	14·	58·
1836	28·	107·	16·	68·
1837	28·	110·	17·	66·
Means	30·	122·	16·	68·

The proportion between the means of the *maxima* and the means of the *minima* appear to be nearly the same, and they agree in showing that the quantity of water yielded by the mines in Slate is about four times as much as by those in Granite. The water drawn from the Greenstone rocks is much less than either.

We have no reliable record of the quantity of water pumped from the mines in the Limestone and other rocks of Derbyshire, Yorkshire, or those of the northern counties. In most of the lead mines the quantity of water is very large, and we know that it bears a close relation to the quantities of rain which falls upon the surface. Much of it is discharged by the adits, but in many of the lead-mining districts—that of Mold in Denbighshire may be quoted in illustration—valuable lead mines have been abandoned, the flow of water being beyond the power of the largest steam pumping-engines.

The greatest quantity of water found in mines is derived from the surface, and it is discovered by experience that, by carefully guarding the surface by an efficient system of drainage—by either preparing channels to carry off the rain-water, or by constructing reservoirs for preserving it—a great economy is effected. The water of course penetrates the earth at different rates and

* Those who may desire to pursue this inquiry should consult Mr. W. J. Henwood's Memoir "On the Quantity of Water in the Cornish Mines," in vol. v. of the "Transactions of the Royal Geological Society of Cornwall."

† "Historical Statement of the Improvements in Cornish Steam Engines." By Messrs. Lean.

in varying quantities according to the nature of the stratum through which it has to percolate. All the fissures, including the mineral veins, form channels through which the waters falling as rain rapidly pass away. In addition to these channels the rocks themselves form vast filtering beds through which aqueous fluids are constantly percolating. The hot springs, to which attention has been already directed, ascend from profound depths; but even those derive their waters from the surface of the land, or from the vast ocean. The circulation of waters is a curious and complex study with which we have not now to deal. It appears necessary to thoroughly receive the idea that the waters which fall on the Earth's surface, and which are so essential to the whole vegetable world and to the animal economy, are derived by evaporation from the "Earth-girdling sea," and are held in suspension as vapour in the atmosphere, forming clouds in all their various conditions, until, by changes of temperature, the saturated air parts with its water in the forms of dew, mist, rain, hail, or snow. As in one of these states the water falls and passes through the fissures, veins, and strata, and penetrates the earth, it eventually arrives at such a depth that it becomes heated and acquires a strong ascensional force, showing itself in this country in hot springs and in other places in the condition of steam.

In 1811 Mr. Joel Lean commenced the publication of his "Engine Reporter," the intention of which was to record the actual work done by the pumping-engines. At first there was much prejudice amongst the engineers, and the mine agents, so that but few of the engines were noticed. The value of the record was eventually admitted, and a large number of engines were included. The following table shows the steady increase of duty to 1856:—

Year.	Approximate Number of Engines reported	Average Duty of the whole.	Average Duty of the best Engine.
1813	24	19,456,000	26,400,000
1823	45	23,156,162	42,122,000
1833	57	46,142,406	83,306,100
1838	61	48,700,000	84,200,000
1843	36	60,000,000	96,100,000
1848	27	53,166,600	
1856	24	47,000,000	

In 1838 the Messrs. Lean reported the average duty of 61 pumping-engines as amounting to 48,700,000 of water 1 foot high by the consumption of a bushel (94 lbs.) of coal; and in the year 1856 Mr. Thomas Lean reported 24 engines as having consumed 19,578 tons of coal, which raised 160,000,000 tons of water 10 fathoms high, being 56,000,000 lifted 1 foot high by 112 lbs. of coal, or 47,000,000 lbs. raised throughout the same space by the consumption of 94 lbs. of coal, showing a decrease 18 years later of 1,700,000 lbs. per bushel. A similar report was published by the late Mr. Browne, of St. Austell, which included 22 pumping-engines in 1856, giving an average duty of 35½ millions of pounds raised 1 foot high by the consumption of 112 lbs. of coal.

The following table will show the principle upon which Lean's "Steam

Engine Reporter" was constructed, and it gives a correct statement of the variations in the amount of work done by the steam-engines constructed for draining the waters from the deep mines of Cornwall. The term "Duty," which is used here, was first employed by James Watt to signify the nett effect resulting from the consumption of a given weight of coal. The expression may be regarded as the term which signifies the amount of force employed and the weight of water lifted, multiplied by the space through which it acts, divided by the weight of coal consumed:—

TABLE SHOWING THE DUTY (WORK PERFORMED) BY SOME OF THE BEST CORNISH PUMPING ENGINES DURING THE PAST FORTY YEARS.

(*From Lean's "Engine Reporter."*)

Year.	Mines.	Engines and Diameter of Cylinder.		Load on Piston per Square Inch.	Actual Horse-power employed.	Number of Strokes per Minute.	Coal consumed per Horse-power per Hour.	Pounds raised One Foot high by consuming 112 lbs. of Coal.	Average quantity of Water drawn per Minute.
			Inches	Lbs.			Lbs.	Millions.	Imp. Gals.
1840	Wheal Darlington	Eastern	80	15·11	—	8·55	—	By bushel coal, 94 lbs.: 84·0	842
	Wheal Vor	Trelawny's	80	15·25	—	8·16	—	59·2	409
	Fowey Consols	Austen's	80	11·65	—	7·20	—	85·2	547
1845	Wheal Vor	Trelawny's	80	15·90	—	7·10	3·5	53·1	962
	Dolcoath	Jeffrei's	76	12·10	—	5·90	4·4	41·5	280
	Great Work	Leeds	60	14·50	—	7·40	3·2	56·9	176
1850	United Mines	Taylor's	85	15·60	221	7·50	2·4	90·0	—
	South Wheal Frances	Tredinnick's	75	10·10	92	6·30	2·9	76·0	491
	Dolcoath	Hocking	76	12·50	101	6·50	5·0	43·0	308
1855	Great Work	Leeds		14·70	87	7·70	3·2	69·0	297
	Wheal Tremayne	Michell's		13·00	59	5·30	3·1	71·0	402
	South Wheal Frances	Marriot's		14·50	60	2·80	3·6	60·0	218
1860	Alfred Consols	Davey's		9·70	87	5·90	2·6	82·6	522
	West Wheal Seaton	Harvey's		7·70	70	4·50	3·9	55·7	292
	Cargoll	Sandy's		15·40	101	5·80	3·9	56·0	492
1865	Wheal Seton	Tilly's		10·30	39	3·30	3·1	70·0	89
	West Caradon	Elliot's		14·20	35	4·20	3·3	65·6	135
	Great Wheal Busy United	Harvey's		22·30	176	4·60	3·6	61·6	506
1870	Wheal Seton	Tegoning's		7·00	40	4·50	3·2	69·1	258
	West Wheal Seton	Harvey's		12·30	90	3·60	3·3	66·6	234
	North Wheal Crofty	Trevenson's	80	15·10	73	3·30	3·9	56·6	234
1875	Crenver and Wheal Abraham	Willyam's	70	11·40	85	6·60	3·3	65·5	601
	West Wheal Seton	Harvey's	85	17·40	224	6·80	3·5	63·2	902
	West Basset	Thomas's	60	16·80	104	8·40	3·5	62·3	383
1880	West Wheal Seton	Harvey's	85	13·80	128	4·60	3·4	64·0	391
	Dolcoath	Loam	85	13·80	96	4·50	3·5	62·7	168
	Mellanear	Gundry's	80	17·20	81	3·10	4·2	52·2	380

The application of the expansive power of steam, and its introduction to the mining world, has been already noticed in the historical sketch given. Hornblower, however, in 1781 invented the double-heat valve, and took out a patent for working steam expansively. This engineer was also the first who employed two cylinders, his engine being since known as the "Combined cylinder engine." The steam was admitted so as to elevate or depress the piston in the first or smaller cylinder, and then allowed to act by its expansion on the larger piston in the second cylinder. The steam employed by Watt was, as it is termed, low-pressure expansive. In 1802 Trevithick and Vivian patented their application of high-pressure principles to the steam-engine. In the notice already referred to, the two Trevithicks, father

and son, are mentioned, and about that time we have the first satisfactory notice of the engineering capabilities of Richard Trevithick, jun. The following account informs us that Trevithick had erected a steam-engine at Wheal Treasury, when he was brought into direct competition with James Watt and Edward Bull:—

WHEAL TREASURY COST, JUNE, 1795.

	£	s.	d.
Richard Trevithick, jun., 13 days at	0	3	6
Richard Trevithick, sen., for expenses at Helston at sundry times, and at other places, waiting on the Adventurers	0	7	6
Richard Trevithick, jun., for moving and erecting the eastern engine	21	0	0
Ditto for one month's attendance on ditto	18	0	0
To Edward Bull for his attendance	2	2	0
To Mr. Bull's engine, for two months' saving respecting his engine	43	12	0

1796, APRIL.

The said Richard Moyle subjects himself to pay any demands which may be hereafter made by Messrs. Boulton and Watt for savings in the same mine.

At a meeting of the Old Adventurers of Wheal Treasury, held this 27th day of March, 1797, at Praze-an-Deeble, it was unanimously resolved that the earnings claimed by Boulton and Watt should not be paid till the validity of their patent should be fully proved.

The elder Trevithick, who has been already mentioned, was an active agent in resisting Watt's patent claims upon the Cornish mines. In August, 1797, "Trevithick's hand was cold, but he had lived to see his son an engineer, competing with Watt. This was a dark time for Cornwall—death, law proceedings, and poverty were rife, and the numerous prosperous mines of twenty years before had dwindled down to bare walls and barren mine-heaps."*

The estimation in which the younger Trevithick was held is related as follows by Captain Richard Eustace: "At Wheal Treasury one of Boulton and Watt's pumping-engines worked badly, and at last stopped. The engineman in charge could do nothing with her. The water was rising in the mine, when Trevithick, jun., offered his services and made things right. His father boasted that the best man in the mine could not do what his boy had done." In 1798 Trevithick was engineer at Herland mine, and was engaged in a lawsuit with Boulton and Watt for infringement of patent, Watt having placed one of his engines on that mine. In 1802 Bull, jun., and Trevithick erected a similar engine, whose cylinder was 60 inches in diameter and placed directly over the shaft, the piston-rod being attached to the pump-rods. Captain Grose stated just before his death, in 1858, that Trevithick was, in 1800, "the head engineer in the county."

In 1800 the younger Trevithick constructed his globular tubular boiler, and in 1811 his cylindrical boiler for Dolcoath engine.† Lean tells us that in 1801 in Crenver and Oatfields, in the parish of Crowan, Trevithick found the pit-work to consist of leathern buckets, with two or three pistons, such as were at that time in general use for plungers, in a very bad state; and it may be safely asserted that the engines were idle at least one-third of the time, repairing the pit-work and changing the buckets. Here Trevithick

* In the revival of mining, Richard Trevithick the younger took an active part. He strove to construct pumping-engines which should not be liable to Watt's patent claims, and he was successful in doing so.

† Lean's "Historical Statement of Steam Engines in Cornwall." 1839.

first introduced his plunger-pole, instead of the common box and piston, wherever he found it practicable.

In 1798 Trevithick erected the water-pressure engine at Roskear mine. Captain Joseph Vivian, the manager of this mine in 1815, says "he re-erected the old water-pressure engine, which was then spoken of, as the first water-pressure engine ever erected with a pole and side-rods." Wheal Druid copper mine appears to have been the first at which Trevithick overcame the difficulties of using water instead of steam. Here he worked at a pressure of 100 lbs. to the square inch.

Gregory says*: "Some further attempts to make pressure engines upon the principle of the steam-engine have failed, because the water, not being elastic, could not be made to carry the piston onwards a little, so as completely to shut one set of valves and open another. In the present (Trevithick's) judicious construction, the tumbler performs the office of the expansive force of steam at the end of the stroke."

In 1802 Trevithick erected a water-pressure engine at Hill Carr Sough, near Youlgreave, which appears to have worked for fifty years, when it was, with several others, sold.

Up to 1800, minerals had been raised by horse-whims from the Cornish mines, in buckets, barrels, or kibbles made of wood and bound with iron. When steam-whims were introduced the breakage of those was greatly increased. This led Trevithick to introduce the wrought-iron kibbles, shaped like an egg with flattened top and bottom, and he also invented a new method for emptying them.

"The new iron kibbals were two or three times as large as the old ones for the horse-whim. The poppet heads were raised that the kibbal might go higher. The landing man said, 'I wonder who is going to land them big kibbals; I shan't land them.' Capt. Trevithick said, 'Can't you wait a bit?' When it was all complete the kibbal didn't want any landing. It turned upside down, and the stuff went into the waggon without any landing or shovelling." †

The new method was to carry the loaded kibble a certain distance above the waggon; a chain from one side and pincers were attached to a hook in the kibble bottom; the loaded kibble was then lowered the required distance, the fixed chain drawing the kibble off the line of the shaft and over the waggon, and at the same time turning it bottom upwards, discharged its contents into the waggon; then a pull on a catch freed the pincers, and the kibble dropped over the line of the shaft ready for descending. This method, introduced in 1800, is still in use, though square boxes of iron on wheels, sliding in guide-rods in the shaft, are now preferred.

With Trevithick's share in the introduction of the steam-engine on tram-roads in Wales in 1803 and at Newcastle in 1804 we have nothing to do in this volume.‡ Rees, in his "Cyclopædia," in 1819, says: "We have an account of a trial of a small high-pressure engine, made in Wales in 1804, to ascertain its powers to raise water. The cylinder was 8 inches in diameter

* Gregory's "Mechanics," 1806.
† "Life of Richard Trevithick." By Francis Trevithick, C.E.
‡ "Life of Richard Trevithick, with an Account of his Inventions." By Francis Trevithick, C.E. 1872.

and 4½ feet stroke. It worked a pump of 18¼ inches in diameter (about 4½ feet stroke), which raised water 28 feet high. It worked at the rate of 18 strokes per minute and consumed about 80 lbs. of coal per hour. This when reduced is about 17½ million pounds raised 1 foot high for each bushel of coals."

R. Trevithick, Andrew Vivian, and William West were partners in the patent of 1802 for Trevithick's high-pressure engine. In 1807 the accounts show that the patent premiums received more than covered the expenses. Hyde Clarke, who knew Trevithick, and whose father was intimate with him, wrote: "The introduction of Trevithick's improvement gave increased power to steam, and it is of that importance that Stuart * is inclined to date the era of the steam-engine, from Trevithick's introduction of high-pressure engines. In the establishment of the locomotive, and in increasing the capabilities of the marine engine, there can be no doubt that Trevithick's exertions have given a far wider range to the dominion of the steam-engine than even the great and masterly improvements of James Watt effected in his day." †

Arthur Woolf was born in 1766,‡ and served an apprenticeship to a carpenter and joiner, in the village of Pool, near Camborne. The substantial benefits conferred by Woolf on his native county require some notice of his labours. He obtained employment as a first-class man in the engineering shop of Bramah at Pimlico. In 1795 Woolf left Bramah's shop to start on his own account. In 1796 he was employed to erect a second-hand Boulton and Watt engine at Newbottle colliery in Durham, which he promised to improve, so that it should consume less coal. This promise he is said to have successfully carried out. Woolf returned to London, and was called in by Messrs. Meux and Company, brewers in London, to assist Hornblower in getting over a difficulty with his patent two-cylinder engine. Being successful, Arthur Woolf was appointed resident engineer to the brewery—receiving at first £2 a week and subsequently £3—which situation he filled until 1806, when he established a steam-engine factory of his own. Woolf applied high-pressure steam and Watt's condenser to Hornblower's two-cylinder engine, and in 1804 he patented this mode of working high-pressure steam. On April 17th, 1811, certificates were published stating that "Woolf's engine, with one bushel of coal, can lift from 30 to 40 millions of pounds 1 foot high, but Boulton and Watt's engine of the same size only from 12 to 13 millions of pounds 1 foot high." Woolf was the first to make a wrought-iron boiler sufficiently tight for high-pressure steam in Cornwall: up to 1817 Woolf had used only his patent cast-iron boiler, when, being examined before a committee of the House of Commons in May of that year, he was led to make some experiments on wrought-iron boilers, which were very successful. §

Woolf selected one of the ablest boiler-makers in Cornwall to assist him,

* "Historical and Descriptive Anecdotes of the Steam Engine." By R. Stuart.

† "Railway Prejudices and Railway Progress." By Hyde Clark, Esq.

‡ "A Brief Sketch of the Life and Labours of Arthur Woolf, Engineer." By Samuel Hocking, C.E. (The late Samuel Hocking was himself a high-class engineer, and erected several pumping-engines for the water companies in London.)

§ See "Partington on the Steam Engine"; "Dodd on Steam Navigation"; Report of the Committee of the House of Commons on Boiler Explosions, May, 1817.

and personally superintended the work. He saw that properly-shaped cylindrical punches were used, that special care was taken in punching the holes, and that all the rivets were made to a gauge of uniform size. Above all, he insisted that no yarn should be used in the joints. Prejudice was against him in this, and his boiler-maker protested that he could not make a boiler tight without yarn. Arthur Woolf's experiment was a complete success, and his boiler was a type for all high-pressure boilers made in Cornwall. Mr. John Taylor wrote the following statement with regard to Woolf: "He made many valuable alterations in the details (among which may be mentioned the remodelling of Hornblower's double-beat valve into the present improved form), introduced a style of manufacture greatly superior to any that had before been known in the county, and formed in fact a new school of engineering there. He seemed to possess an almost inexhaustible mine of invention. His improvements in detail were almost innumerable, for scarcely a single part of the engine could be named, however apparently unimportant, which did not receive some beneficial alteration at his hands. His talent for contriving tools was very great, and he seemed to have almost an intuitive perception of the best method of performing operations and processes of all kinds." *

A more appropriate place than this cannot be found for a short statement of the several valves introduced in the Cornish steam-engines.

Hornblower's valve, Fig. 168, has been described in many publications. A very good account of it will be found in "Gregory's Treatise on Mechanics," vol. ii. page 378.

Woolf, to render easy the handling of his large-sized engines, invented the double-beat valve shown in Fig. 169, and first applied it to a 90-inch cylinder

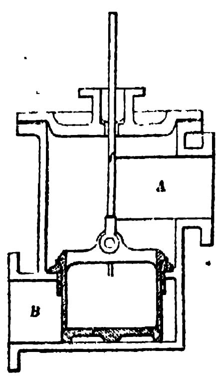

Fig. 168.—Hornblower's Valve.

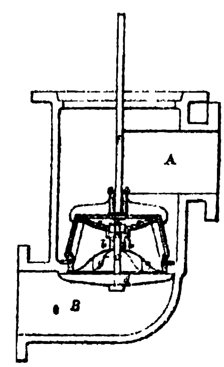

Fig. 169.—Woolf's Valve, Consolidated Mines Engine, 1823.

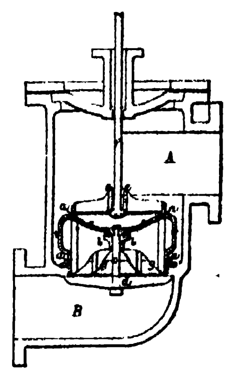

Fig. 170.—Woolf's Valve, Wheal Alfred Mine Engine.

engine, which he erected at the Consolidated mines, in Gwennap, about the year 1820. This valve answered its purpose very well, and continued in action for many years; but was not repeated, for Mr. Woolf soon afterwards changed its form to that shown in Fig. 170, which improved valve he first applied to the Wheal Alfred engines about the year 1823; since which time this form of valve has undergone no change, and is now known out of the county as the Cornish double-beat valve.

* Contributed by Mr. John Taylor to Pole's Work on the Cornish Engine.

The mode of working may be easily understood from an inspection of the drawing, Fig. 170. *o o* is a ring of gun metal, having an inclined face turned upon its upper and inner face, as shown—this forms the lower "beat" of the valve. From the interior of this ring spring the radial arms *g g*, which meet at the centre of the valve in the boss *b*. At their upper edge they unite in the concave plate *s s*, upon the outer edge of which is turned the conical face, which forms the upper "beat" of the valve.

The boss *b*, with its ring *o o*, ribs *g g*, and its upper concave plate *s s*, is cast in one piece, and held down in its place by means of the bolt *c* and cross-bar *d*, thus forming the "valve-seat."

The movable part or valve proper consists of a ring of metal *v*, with turned surfaces at *a a*, *á á* joined by radial arms to the boss *e*, into which the spill *f* is fixed, is shown in the drawing as if closed, the turned surfaces at *a a* and *á á* being in contact. In this position no steam can pass from A to B, or *vice versâ*, for all communication is shut off by the "beats" of the valve itself—the plate *s s* at the top, and the ring *v* of the valve itself. When the valve is lifted, the steam is at once able to pass in two ways—first, directly through the opening *á á* at the lower "beat," and secondly, between the radial arms of the valve—through the upper seating *a a*, thence between the ribs of the valve-seat *g g*, to the opening below.

The lettering is the same, for similar parts, of all the three figures.

It is not the author's purpose to enter more closely into the question of the Cornish pumping-engine than is necessary to convey a correct idea of its main principles of action, and incidentally to direct attention to a few names, which deserve high praise, for the thoughtful ingenuity which the men who bore them gave to the improvement of the application of steam-power to the drainage of our deep mines.

While on the subject of valves, a brief notice of two or three valves which have been more used than any others in our mines may be given here. For further information on this subject the reader is referred to Mr. Stephen Michell's book on Mine Drainage.*

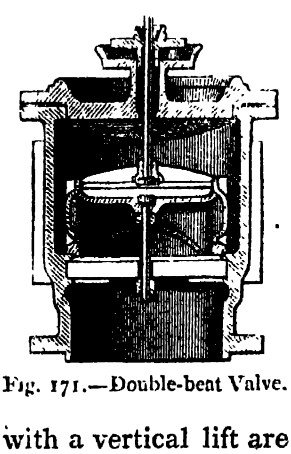

Fig. 171.—Double-beat Valve.

The valve represented (Fig. 171) may be regarded as a type of the clack-valves. The ordinary clack-valves are hinged to the seat, with rivets or pins, working in a recess or slot. These are used extensively in the Cornish pump-lifts.

Mr. Teague originated a clack-valve with a series of perforations, over which circular pieces of india-rubber work. Valves on this principle, being noiseless, have given satisfaction, being considered an improvement on the ordinary clack-valves. Valves with a vertical lift are of various kinds, known as cap-valves, wing or mitre valves, spill or mushroom valves, and ball-valves. Harvey and West's double-beat valves are the best known of this variety. These valves have a large lifting area, a spacious water-way, and consequently a low lift. Where

* "Mine Drainage, being a Complete and Practical Treatise on Direct Acting Underground Steam Pumping Machinery." By Stephen Michell. Crosby Lockwood & Co. 1881.

the water is free from grit these valves are the best, but the presence of grit in the dirty water of the mines renders them objectionable in the Cornish mines.

Fig. 172 represents Husband's four-beat valve, which is an extension of the principle already named. "Some of these engines (direct acting) used for pumping water for the supply of towns make an upstroke of 10 feet in a second, with poles reaching a diameter of 50 inches, and this valve allows the water to pass with such freedom that the valve is closed at the moment the up-stroke is completed, and there is consequently no loss of water, or any shock. About sixteen years since valves on this principle were used for a pump for raising water from a depth of 320 yards in one lift, at the Eagle Bank colliery, Yorkshire, and they acted without shock under that great head of water, and are at work to the present day." *

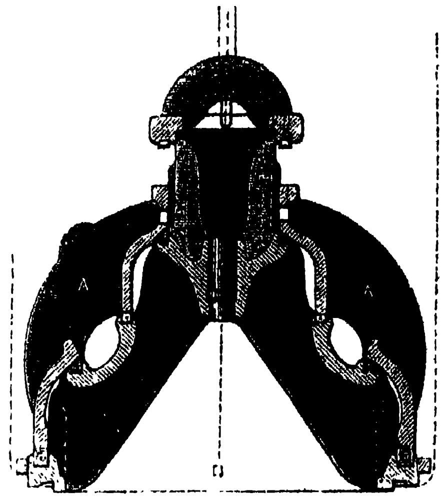

Fig. 172.—Husband's Four-beat Valve.

Mr. James Simpson designed a valve formed of three rings, or annular valves, the inner and outer edges of which have beats. Each valve is separate and the lift is independent of the others. This is mainly used in engines for waterworks.

We have spoken of the important improvements made by Woolf in the steam-engine. Useful as these were, they were surpassed by the high-pressure boilers which he introduced. Low-pressure boilers were made of wrought iron, some of them had as many as 1,500 rivets, each of which, says Mr. George Dodd,† "in some measure answered the purpose of a safety-valve;" that is to say, they allowed high-pressure steam to escape. The following remarks by Mr. James Sims ‡ are much to the purpose :—

"I commenced engineering in the year 1811, at a period when the steam-engine was in a very rude state, and from that time to 1814 little or no improvement in the mode of constructing the steam-engine took place, but was carried on just as left by Boulton and Watt, and their active agent, Mr. Murdock. The increase of duty was, therefore, only just as follows, taking the three following years of 1812, 1813, 1814. Average duty in 1812 was 19·3 millions; 1813, 19·5 millions; 1814, 20·6 millions. In the latter part of 1814 Mr. Arthur Woolf erected one of his patent combined cylinder engines, and with great success, when compared with those of Boulton and Watt. The duty of Woolf's engine having risen to 52·3 million pounds, lifted one foot high by the consumption of one bushel of coal, and he having improved several Boulton and Watt engines, by causing them to work

* "Pumping Machinery." By W. Husband, C.E. ("Proceedings of the Mining Institute of Cornwall," vol. i. No. 5, page 167.)
† Report of Committee of House of Commons on Boiler Explosions, May, 1817.
‡ "History of the Cornish Engine" (Mining Almanack, 1849).

more expansively by using higher steam, awakened the whole of the Cornish engineers to a new era in steam power; and many a *sleepless night have I had with others, in repairing the many breakages of engines and boilers, caused by the boilers being too weak for the steam attempted* to be used, and the materials of the engine not being strong enough for the concussion given, by the sudden admission of much higher steam on the piston than was originally intended."

Early in 1815 Woolf was employed by the managers of Dolcoath mine to report on the efficiency of the steam-boilers belonging to their large engine, as there was difficulty in raising steam from them to meet the requirements of the engine, which was getting more heavily loaded as the mine deepened. He found the boilers of ample capacity, and coal enough consumed to give the necessary quantity of steam; and the fact of their not doing so was proof to him that much of the heat was escaping to the chimney, which, on examination, he found was the fact. He simply removed the outlet passage to the chimney from the *highest* part of the flue to the *lowest*, when it was found the steam-giving power of the boilers, under the altered condition, had so increased, as to render it unnecessary to add the contemplated new boiler. This simple alteration placed the pumping power of the mine in a condition that so greatly pleased the Adventurers that they not only paid Woolf handsomely for his professional services,* but advanced also the wages of their engineers on the mine, Jeffery and Gribble, who had but recently been appointed. Richard Jeffery, as a young man, had been working with the engineers in Dolcoath mine for some years; James Gribble was an engineman at Stray Park mine, from which situation he was removed to join R. Jeffery, as engineer of Dolcoath mine, in June, 1812.

Woolf, on his inspection of the machinery, &c., at Dolcoath in the year 1815, was much pleased with Gribble, and often said he was the most promising young man for his profession he had met with in Cornwall. He was ever afterwards his personal friend and adviser on all engineering questions.

Dolcoath new engine, erected by Jeffery and Gribble in 1816, has often been referred to, to show how near other engineers, using single cylinders (Boulton and Watt form), approached the duty done by Woolf's two-cylinder engines. The facts are as follows:—

"Soon after the time of Woolf's inspection, early in the year 1815, Dolcoath Adventurers, finding it necessary to provide for the further deepening of the mine, decided on erecting a new and more powerful engine, and intrusted its construction to their own engineers, Jeffery and Gribble. Gribble, being the ablest man of the two, had the most to do with preparing the drawings for the construction of the several parts of the said engine, some of which were made at Neath Abbey, some at Perran Foundry, and most of the wrought ironwork was forged and fitted on the mine. Every drawing was submitted by Gribble to his friend Arthur Woolf for his correction and approval before it was issued as orders to the different factories, &c., where the piece was made."

* The Mine Cost Book for March, 1815, shows that Woolf was paid for his professional services.

The success, therefore, of the Dolcoath engine, erected by Jeffery and Gribble in 1816, was mainly due to the fact of its having been constructed under the supervision of Mr. Woolf, and in accordance with his patent of 1804, wherein is *specified* how high-pressure steam may be safely employed in engines of Boulton and Watt's construction, "by making all the parts stronger, and properly proportioning the valve that admits the steam from the boiler on to the piston."

A portion of his specifications reads as follows:—

"With regard to steam-engines in which the separate steam measure (referred to in 4th clause) may not be thought advisable, the same may be improved by the application of my aforesaid discovery, by making the boiler and steam case in which the cylinder is enclosed much stronger than usual, and by altering its structure and dimensions of the valve admitting steam from the boiler into the cylinder, in such a manner as that the steam may be admitted very gradually at first, afterwards more freely. The reason for this precaution is this,—steam of such great elastic force as I employ, if admitted suddenly into the cylinder, would strike with a force that would endanger the safety and durability of the engine. Due and effectual means must be used to keep up the requisite temperature of all the parts of the apparatus into which the steam is admitted, not intended to be condensed."

The name of West has been mentioned more than once in these pages. As a self-educated man, who placed himself in the first rank of Cornish engineers, some brief notice of him, and of his works, is required.

It is an interesting link between Trevithick and William West, that the latter well remembered holding a candle to the great Cornish engineer, while the "Catch-me-who-can" was in process of construction.*

Mr. F. Trevithick, in the "Life of Richard Trevithick," says the three Wests, all skilful mechanical engineers, were employed at Dolcoath in 1816. These were workmen, when Jeffery and Gribble erected their 76-inch engine, fitted with a double-beat valve. When about sixteen or seventeen William West was employed by his brother-in-law, and subsequently he was engaged by Captain Joseph Vivian as working engineer, in erecting a pumping-engine at North Roskear. This engagement led him frequently to Hayle Foundry, and his abilities attracted the attention of a member of that firm, who introduced him to the Messrs. Bolitho, of Penzance, for whom he erected an engine to drive a flour-mill. William West was next engaged as working engineer by Captain Nicholas Vivian, and employed in charge of two pumping-engines of 80-inch cylinder, erected in 1827 by Captain Grose. William West in 1831 entered the employment of Mr. J. F. Austen (afterwards Trefry) as engineer of Fowey Consols and Lanescot mines. In 1834 52 engines reported an average duty of 47·8 millions, the average duty of the best engines this year being 90·9 millions. This shows how greatly the engineers named had improved the Cornish pumping-engine.

"Mr. William West erected a new 80-inch cylinder engine at Fowey Consols mine, in constructing which he had availed himself of all the improvements that had been made for some years; and as he had filled the

* The name of Trevithick's locomotive, which was worked near Euston Square in 1808.

situation of deputy engineer at Wheal Towan at the time when Captain Grose was so successfully carrying out his views on the subject, he was enabled to construct a machine which exceeded any hitherto known. Austen's engine was reported for the first time in July, 1838. Its average duty for that month was 90 millions, and for the following September 97,856,382." *

An experimental trial of Austen's steam-engine, of 80-inch cylinder, at the Fowey Consols mine, which was conducted with the utmost care, shows that this machine gave the extraordinary duty of 125,000,000.†

In addition to several other mechanical appliances of great excellence, the boilers of West and Petherick excited much attention. The judges of the Polytechnic Society‡ say: "The principal improvement in the construction of these boilers consists in their having a horizontal cylindrical tube enclosed within the tube which contains the fire. The water is supplied from the feed-pump to the inner tube around which the fire is arranged, and the steam and heated air pass from it to the boiler, and from thence to the steam-pipe."

Mr. West erected, in 1835, a steam-capstan on South Hue mine, the first of its kind ever put up. This excellent Cornish engineer was next employed to erect engines for the East London Waterworks, for which he devised a double-beat valve, and he also patented some improvements in valves, the chief advantages of which were—facility of adaptation to the degree of pressure; readiness of renewal; simplicity of construction and form; easy and equal action; adaptability to any position; and cheapness as the result of this simplicity.

In connection with Mr. John Darlington, Mr. W. West in 1867 patented a system for counterbalancing pumping-rods, changing the angles of reciprocatory motion and transferring power.

In conducting mining operations at any considerable depth below the day level, it is frequently necessary to counterbalance the pump-rods by means of levers or "balance bobs" placed at the surface of the ground, or in cavities excavated horizontally out of the side of the shaft.

Although a weighted lever has been employed for this purpose since the year 1770, yet its use is open to some objection, inasmuch as the action of the counterpoise is never strictly in the line of pumping motion, and the space required underground is only obtainable at a great expense.

When a vertical shaft has struck the lode, and it is designed to continue the sinking upon the lode itself, the pumping motion is transferred to oblique rods by a simple joint and bar or "fend off," or by means of a bell-crank or V-bob—arrangements not only causing much friction, but expensive and troublesome to keep in order.

Sometimes it is desirable to work pumps in two or more shafts by the same engine. The motion is then communicated from one shaft to the other by horizontal or flat rods supported on rollers, the direction of the motion being changed by bell-cranks as in the former case. This arrangement

* Lean's "Historical Statement of the Steam Engine in Cornwall," 1839.

† See a description of this engine in the "Transactions of the Institution of Civil Engineers," vol. i. 1836; and De la Beche's Report on Cornwall, Devon, and West Somerset.

‡ Report of the Royal Cornwall Polytechnic Society, 1834.

absorbs considerable power, unless the rods are well and truly supported, and great attention paid to the proper lubrication of the bearings.

It was proposed to supersede these several appliances by the apparatus shown, Figs. 173 and 174, which will be rendered clear by the following brief description. One arrangement may be said to be a modification of the other, since in each piece of apparatus advantage is taken of the incompressibility of water, which is so confined as to constitute, as it were, an *hydraulic bar*, acted upon by means of plungers or pistons.

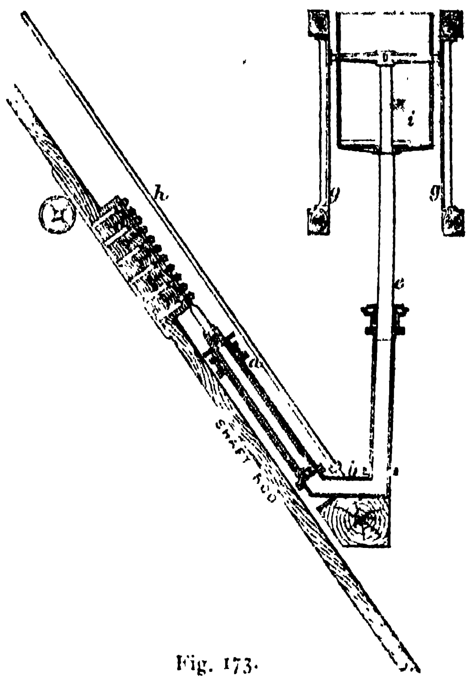

Fig. 173.

Diagonal Shaft Rods (Fig. 173).—These are counterbalanced by means of two plungers, one of which is provided with a weight-box.

(*a*) Plunger attached to main-rod.
(*b*) Pipe connecting the ram-case *d*.
(*e*) Plunger with weight-box.
(*g*) Guides for weight-box.
(*h*) Pipe communicating with cistern for supplying such water as may be necessary to make up leakage.
(*i*) Small supply plunger which may be attached to the apparatus when the pipe *h* cannot be advantageously introduced.

The communication between the faces of the two plungers is entirely free, and hence, if the acting ram *a* be raised, the balance-plunger *e* will fall and counterbalance the rods to the extent of its weight less the trifling amount of friction incident to the movement.

Fig. 174 shows the arrangement for a vertical shaft, the power being taken from the pumping-rod at one of the underground levels.

(*a*) Main-rod.
(*b*) Supply-pipe.
(*c*) Water-main.
(*d*) Pumping-ram fitted with side rods.

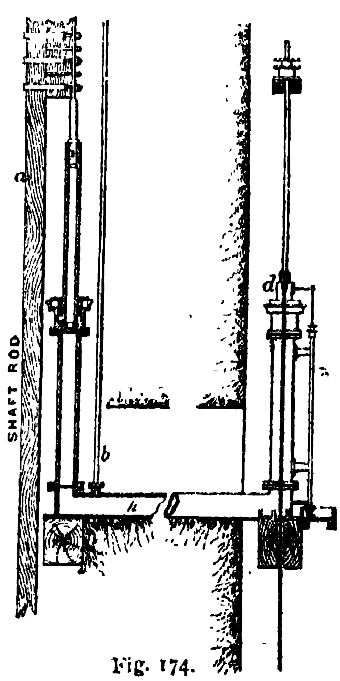

Fig. 174.

Vertical Shaft Rods (Fig. 174). — The counterpoise arrangement is shown, in which the parts are similar to the apparatus illustrated above.

(*a*) Motive-ram fixed in vertical shaft.
(*b*) Pipe connecting vertical with inclined plunger-case.
(*c*) Plunger, carrying weight-box. (See Fig. 173.)

(*g*) Guides for weight-box. (See Fig. 173.)

(*h*) Water supply pipe.

Transfer of Power.—The apparatus for this purpose may be single or double acting. If single, an acting and pumping ram, coupled by a main of pipes, will suffice. When double, the acting cylinder must be furnished with a piston, forcing to a pumping-ram in one direction and lifting a pumping-ram set elsewhere.

In the apparatus described it is evident that the reciprocatory movements are unaffected by the position of the cylinders, and that these may be placed either vertically or at any angle best suited to the special exigencies of the situation. Neither is the motion affected by the distance between the cylinders, nor by any abrupt windings or angular directions which the passage between the cylinders may present. In counterbalancing pump-rods, the apparatus requires but little room, whilst the movement of the weight-box bears directly upon the line of pumping motion without occasioning side or vibratory strain.

As a substitute for angle bobs, the hydraulic arrangement presents some special advantages, inasmuch as it will sometimes be found to obviate the necessity of employing a balance-beam; and as the pumping-rod is not subjected to any cross strain, it follows that it may be permanently and properly guided, and "rubbing" pieces are rendered unnecessary.

The transfer of power to any reasonable distance, whether at surface or underground, may also be effected at a loss in friction much less than would arise from the usual mode of transmission, whilst the pipes for the retention of the water may be buried, carried down the corner of a shaft through levels, and into the remotest heading, without causing the least inconvenience.

At the Wildberg mines, Prussia, where hydraulic principles were early applied, an engine with a ram 3 inches in diameter was placed 50 fathoms below the surface, and 2,400 feet from an accumulator, weighted to 800 pounds to the square inch. The engine drew plungers and buckets 5½ inches in diameter, and enabled a piece of ground to be developed which otherwise could not have been attacked for an indefinite period. A rotatory pressure-engine at the same mines was constructed with two cylinders each 2 inches diameter, and having a stroke of 9 inches. By adjusting the stop-valve the speed could be made to vary from 2 to 20 revolutions per minute. Overwinding was prevented by a contrivance placed between the skip and stop-valve, which closed the latter at the required time. These rotating engines are applicable to driving capstans, stamping, and crushing mills. In mines where no surface water is available for effecting the concentration of the ores, and where an engine has to circulate water for this purpose, passing it, as is sometimes done, over water-wheels, one pressure-engine, having two cylinders each 3½ inches diameter, may be made to take the place of a water-wheel 30 feet in diameter.

The hydraulic bar and accumulator system have various forms of adaptation; for transferring power by single or double acting apparatus, for counterbalancing shaft-rods, counterpoising flat rods, or changing vertical into oblique motion. The transferring apparatus, which may be applied to

inclined shafts, or for lifting water from the deep to the rise in colliery operations, was introduced at the Phœnix mines, near Liskeard, where the power was transferred 900 feet below the surface and at a distance of 700 feet from the shaft.

The largest and most powerful hydraulic machinery erected in this country for mining purposes was devised by the late Mr. John Darlington, of Minera, Wrexham. About the year 1838 certain people, mostly residing at Bakewell, decided to extend the operations at the Alport, Magpie, Hubberdale, and Longstone Edge mines in Derbyshire, and to that end it was necessary to drive adit levels and to erect pumping appliances. Early in the year 1841 they availed themselves of the technical ability and mining experience of the late Mr. Darlington. At Magpie and Hubberdale he erected powerful steam-engines of the Cornish type for the purpose of draining the mines. At Longstone Edge the ground was unwatered by means of an adit level; while at the Alport mines he augmented the drainage power by means of three hydraulic engines, two of which were placed in Guy's shaft, and the third in a shaft on the Stanton side of the property. The water for these engines was obtained from the Lathkill and Youlgreave streams, which came together at the village of Alport. After a portion of the water had done its work in the engines it was discharged with the water from the pump-head into the Hill Carr Sough, an adit level about three miles in length, extending from the mines to the river Wye in Darley Dale. The engines in each case consisted of a direct single-acting pumping cylinder fixed directly over the pump. To the larger engine was attached a plunger-pole 42 inches diameter and 13 feet stroke, and to the smaller one a bucket 36 inches diameter and 10 feet stroke. In wet weather these engines made about 5½ strokes and lifted 6,000 gallons of water per minute. The large engine was fitted with two cylindrical valves, a cylinder with balanced pistons for lessening the flow of water at the terminal portion of the stroke, and with a relief-valve for mitigating the force of any shock which might be consequent on bringing the column of water to a state of rest too quickly. In the small engine the water was admitted to, and emitted from, the pumping cylinder through a nozzle cylinder fitted with differential pistons, which pistons received their movement through a tumbling ball shifting a pair of small balanced pistons. The valves used in connection with the pumping plunger were, in the first instance, formed with two beats, contrived by Messrs. Harvey and West, of Cornwall; but subsequently they were replaced by single-beat cylindrical valves arranged by Mr. Darlington. Both bucket and clack in connection with the small engine had leather valves, six in number, beating upon seatings inclined upwards towards the centre. These, with the third engine referred to, worked continuously for a period of about ten years, when the Alport mines were abandoned. Other engines of a similar character were, however, erected by Mr. Darlington at the Lisburne, Cwm-ystwyth, Tarlagoch, and Minera mines in Wales.

In addition to these hydraulic engines, Mr. John Darlington designed, about the year 1837, for use at the Haarlem Lake, in Holland, a compound Cornish steam-engine, the high-pressure being placed within the low-

pressure cylinder, while for very heavy mine pump work he advocated the employment of two direct-acting steam cylinders coupled together and set over the shaft so as to allow of the passage of the capstan rope direct, between the two cylinders, to any part of the pitwork.

At the Minera mines he introduced an apparatus system for bringing up and letting down the miners, and for hauling the ore and vein stuff to surface. As a "man machine" for use in metalliferous mines, it is not likely to be surpassed either for its cheapness or simplicity of parts. For a period of twenty years, during which the apparatus has been in constant operation at the mines referred to, it has proved to be thoroughly efficient, safe, and satisfactory.

In 1848 Mr. John Darlington undertook the management of the Minera mines, and with an expended capital, and workings but half drained, he projected certain exploratory works, which led to the immediate discovery of large and remunerative quantities of lead ore, while he established and maintained the success of the undertaking until his death, which occurred on the 27th of April, 1877.

From the notices which have been given of the progress made in the improvements of the Cornish pumping-engines, a general idea of the principle and power of this application of steam may be arrived at. One or two additional advantageous improvements were made. In the first instance, we must mention Sims's engine. In 1815 Trevithick applied his patent plunger at the Herland mines in Gwinnear. This engine did not answer, and Mr. Sims entered into an arrangement for the use of Trevithick's invention. By combining Trevithick's pole with a Boulton and Watt's engine, Mr. Sims realised a duty, at Wheal Chance, in 1817, of 49,900,000. Several similar machines were erected. In 1825 Captain Grose erected a 60-inch cylinder at Wheal Hope, and was the first to introduce a system of clothing to prevent radiation of heat. By this he raised the duty to 62,000,000, which he further augmented in an 80-inch cylinder engine which he erected at Wheal Towan in 1828 to 87,000,000. The following table was compiled by the late John S. Enys, of Enys, a gentleman to whom Cornish mining is under large obligations for the painstaking inquiries which he carried out, especially in relation to the duties of engines:—

Engines.	Newcomen's.	Watt's Low Pressure. Often Expansive.	Watt's High Pressure Expansive.
Largest cylinder in inches .	77	63 (double)	90 single
Load in pounds per square inch	6 to 7½	6 to 9	3 to 18
Period of use	1720 to 1778	1778 to 1812	1812 to 1828
Highest duty in million pounds .	3 to 7	12 to 9	20 to 93
Average duty in million pounds		19½ in 1793 17½ in 1779	about 50
Depth of mines in fathoms .	90	200	290

The *modus operandi* of the Cornish engine is as follows: A cataract, or mechanical appliance, is connected with the valve gearing, and so set as to control the speed of the engine. In single-acting engines steam from the boiler acts only on one side of the piston, while the other is open to the con-

denser. With the admission of steam the motion of the piston commences, which at the same time lifts a considerable counterpoise depending from the opposite end of the main beam, known as the pump-rods. After the steam has been admitted through the requisite space, the admission or steam valve is shut, and the movement of the piston is continued to the termination of the stroke by the impetus communicated to it at the commencement of its course and by the expansion of the steam. Consequently, from the period of cutting it off, the velocity of the piston decreases to the end of its course, whilst the resistance remains the same.

At the end of the stroke the outlet or eduction valve closes, and the equilibrium, or valve between the upper and lower portions of the cylinder, opens, allowing thereby the steam above the piston to expand on its under side, thus establishing an equilibrium between the two faces of the piston. At this moment the pump-rod or counterpoise begins to descend, and brings the piston to the top of the cylinder. When the piston has nearly obtained this position the equilibrium valve shuts, and the steam intercepted at the top of the piston is gradually compressed until the engine is brought to a state of rest. The steam and outlet valves are again opened by the action of the cataract, and the motion is thus continued.

The cylinder in the Cornish engine is fixed in such a position that the condensed steam in the jacket can return to the boiler. A temperature in the latter of 84° was only lowered 7° in the jacket, so well was it protected by clothing. Little waste of steam is caused by the intermediate space between the valves and piston, since the former are fixed as close to the cylinder as is possible. The whole amount of friction, including imperfect vacuum, is found not to exceed 3¼ lbs. per square inch. In many machines the steam is wire-drawn on its entrance into the cylinder, it being urged that if it were admitted on the piston, beyond a certain pressure the impact would be liable to injure the working parts. There is, however, no valid justification for the employment of this system, since we have only to increase the size of the pipes and valves to obtain an equal effect with steam of less pressure in the boiler.

The term "Duty," as previously explained, is the nett effect produced from the consumption of a given quantity of coal. In Cornwall the diameter of the cylinder of a steam-engine is employed to convey an idea of its power; but its economic performance is invariably determined in relation to the quantity of coal consumed to produce a given effect. This expression may therefore be formulated as the *amount of force* and *weight of water* lifted, multiplied by the space through which it acts, divided by the weight of coal consumed $\frac{(f \times s)}{c}$. Messrs. Boulton and Watt appealed to this test of the efficiency of their engines when engaged in ascertaining the saving of coal due to their invention, and referred to it in all disputes respecting their legal rights. Watt also invented a *counter* to record the number of strokes made by an engine, which counter was usually attached to the main beam. This instrument has been subject to several modifications. Mr. Newton, the philosophical instrument maker of Camborne, has constructed a counter of great delicacy, possessing many advantages.

It will be interesting in this place to give some examples of the large improvement which has been made in some recently-constructed pumping-engines, which are applicable to pumping from deep mines. From the official statement of the trial made in February, 1883, the following particulars are obtained. The engines under trial were two independent compound rotative beam-engines, constructed by Simpson and Company, London, for the West Middlesex Water Works, Hammersmith.

These were compound Woolf beam-engines, the high and low pressure cylinders being on the same side of the beam and opposite to the crank.

The pump, which is double-acting, with four valves, is placed at the end of the beam opposite to the cylinders.

The cylinders are completely steam-jacketed with boiler steam; the low-pressure cylinders have separate steam and exhaust valves.

The coal used was Nixon's Navigation Welsh, obtained from Messrs. William Cory and Sons, and was of very good quality.

Three boilers were used on the trial, each 6 feet diameter by 28 feet long, the flues being 3 feet 6 inches diameter, and each fitted with six Galloway tubes. The feed water was taken from the hot well and pumped direct into the boilers.

The leading dimensions were—

	Ft.	ins.
Diameter of Small Piston	2	5
Stroke of Small Piston	5	5
Diameter of Large Piston	3	$11\frac{1}{8}$
Stroke of Large Piston	8	0
Diameter of Main Pump	1	$5\frac{10}{16}$
Stroke of Main Pump	8	0

The engines were each to pump 3,456,000 gallons in 24 hours, and the duty to be done, under the contract, was not to be less than 96·4 million foot lbs. per 112 lbs. of coal, after 5 per cent. had been deducted from the pump displacement.

OBSERVATIONS TAKEN.

Date of Trial.	Duration of Trial.	No. of Engines.	Revolutions from Counters.	Average Lift of Water.	Boiler Pressure.	Barometer.	Vacuum.	Temperature of Injection.	Temperature of Air Pump Discharge	Coal used.
1883.	Hours.			Feet.	Lbs.	Inches.	Inches.	Degrees.	Degrees.	Tons.
February 7th	24	7	25,920	187·7	50	30	28·5	46	72	3·377
,, 9th	24	8	26,325	187·2	50	29·6	28·1	46	77	3·425

RESULTS.

No. of Engine.	Actual Horse-power in Water lifted.	Coal consumed per actual Horse-power per hour.	Duty per 112 lbs. Coal in Million foot lbs.	Average indicated Horse-power.	Coal consumed per indicated Horse-power per Hour.	Gallons pumped in 24 Hours after deducting 5 per cent.
		Lbs.				
	164·35	1·91	116·1	206·47	1·53	4,160,913
	166·46	1·92	115·5	206·02	1·55	4,225,926

The following extracts from the engineer's report place the trials in a satisfactory light:—

"The first trial with No. 7 engine took place on the 7th inst., commencing

at 11 o'clock A.M., and continued for 24 hours, ending at 11 o'clock A.M. on the 8th inst. The engine made 25,920 strokes, or an average of 18 strokes per minute, and pumped 4,160,913 gallons of water, an average of 187·7 feet high, and consumed 3 tons 7 cwts. 2 qrs. 4 lbs. of coal, which gives a result of 1·91 lb. of coal consumed per pump, or usefully exerted horse-power, per hour, being 17 per cent. less than the guaranteed quantity. This result is equivalent to a duty performed of 116,100,000 lbs. of water lifted 1 foot high with 1 cwt. of coal; the pump horse-power was 164·35, and the indicated horse-power 206·47.

"The next trial, with No. 8 engine, took place on the 9th inst., commencing at 12 o'clock noon, and continued for 24 hours, ending at 12 o'clock noon on the 10th inst. The engine made 26,325 strokes, or an average of 18·28 strokes per minute, and pumped 4,225,926 gallons of water, an average of 187·2 feet high, and consumed 3 tons 8 cwts. 2 qrs. of coal, which gives a result of 1·92 lb. of coal consumed per pump horse-power, being 16½ per cent. less than the guaranteed quantity. This result is equivalent to a duty performed of 115,500,000 lbs. of water lifted 1 foot high with 1 cwt. of coal; the pump horse-power was 166·46, and the indicated horse-power 206·2."

The contract for these engines was very stringent, for not only had the pump piston and valves to be proved quite tight to the engineer's satisfaction before the trials, but 5 per cent. was to be deducted from the pump displacement. As this is not usually done, we have given in the following table the results without deducting the 5 per cent., in order that a comparison may be made between the trials of these and other engines. The pump pistons and valves were tested, and found quite tight under the full head before the trials, and there can be no doubt but that the pumps delivered a quantity of water equal to their displacement.

No. of Engine.	Actual Horse-power in Water lifted.	Coal consumed per actual Horse-power per Hour.	Duty per 112 lbs. of Coal.	Gallons of Water pumped in 24 Hours.	Feed Water per indicated Horse-power per Hour.	Feed Water evaporated from Temperature of Hot Well per lb. of Coal excluding Jackets which circulated back to Boilers.
		Lbs.	Foot lbs.		Lbs.	Lbs.
	173·00	1·821	121,779,242	4,379,903	14·56	9·54
	175·19	1·825	121,512,329	4,448,343	14·78	9·53

It may be remarked that no increase has been effected in the economical performance of the Cornish pumping-engine in Cornwall for many years, and it is thought that this cannot be expected until steam of a higher pressure and expanded to a corresponding degree be employed. The idea is gaining ground among Cornish engineers that advantage will be gained by doing away with the parallel motion by running the piston-rod in guides. It is also proposed to fix the steam valve on the cylinder cover, and the equilibrium in the piston, as well as to work the steam expansively on both sides of the piston instead of one side only.*

* This question is more fully discussed in the "Records of Mining and Metallurgy," by Phillips and Darlington; and those who are interested in the important problem of the best mechanical appliances in use for drainage of mines, should consult also Mr. Stephen Michell's work on "Mine Drainage, being a Complete and Practical Treatise on Direct Acting Underground Steam Pumping Machinery."

In Cornwall slow combustion is usually considered desirable, and boilers are usually made of large dimensions. At East Wheal Rose, Michell's 85-inch cylinder, 10 feet stroke, was furnished with four boilers of the following dimensions: two 36 feet by 6 feet, one 38 feet by 6½ feet, and one 34 feet by 6 feet, weighing together 45 tons. The steam is raised to a maximum pressure of 30 lbs. per square inch, and the consumption of coal, when making 4 strokes per minute, was 3·6 lbs. per horse-power per hour.

Mr. Wickstead,* who made many experiments on Cornish cylindrical boilers, writes: "My experiments upon four Cornish boilers show that, when the consumption of coal per square foot of grate per hour was only 2·475 lbs. and the water evaporated per hour equal to 23·5 cubic feet, 8·258 lbs. of water were evaporated from 80° by 1 lb. of coal, and when the coals per square foot of fire-grate were equal to 5,013 lbs., or rather more than double, 8·605 lbs. of water were evaporated from 80° by 1 lb. of coal, showing an advantage of 4 per cent. in favour of the more rapid combustion and evaporation.

"The following table shows the mean results of all my trials upon *four cylindrical boilers*, lasting 504 hours for quick combustion and 514½ hours for slow combustion :—

Combustion.	Lbs. of Coal per Hour.	Cubic Feet of Water per Hour.	Lbs. of Coal per Square Foot of Grate per Hour.	Lbs. of Water evaporated per lb. of Coal from 80 Degrees.	
Quick	342	46·9	4·682	8·524	100·
Slow	188	25·4	2·596	8·421	98·8

"We some years since experimented on two tubular boilers applied to an 80-inch cylinder pumping-engine, at Par Consols mine, in the county of Cornwall, in order to ascertain their evaporative powers. These boilers were each 32 feet in length, 6 feet 3 inches in diameter externally, and 3 feet 10 inches internally. The fire-grate was inclined towards the bridge, having a length of 6 feet with a breadth of 3 feet 10 inches. They were also provided with an arrangement by which the feed-water was heated to near the boiling-point before entering the boilers. . . . . The water was heated to about 212° by means of the heat absorbed from the gases passing through the flues, and of which the temperature was reduced to about 300° before being discharged through the stack. The heating surface of both boilers was 1,900 square feet, and the warming apparatus 500 square feet, or together 2,460 square feet. . . . . Arrangements having been made for measuring the water, the experiment was begun; and, at the expiration of 46½ hours it was found that 95 cisterns of water had passed into the boiler, and that 11,730 lbs. of coal had been consumed, in order to evaporate 119,700 lbs. of water from the temperature of 92° Fah., which gives 10,204 lbs. of water evaporated from that temperature for every pound of coal consumed. If we take 212° as the standard temperature, we find that each pound of coal had evaporated 11,428 lbs. of water from the boiling-point."

The author, when acting as Secretary to the Royal Cornwall Polytechnic Society, was induced to make a series of experiments "on the quantity of

* "Wickstead on the Steam Engine."

air supplied to the fire-places of Cornish engines." The results of this inquiry were as follows, which are reprinted from the Transactions of the Society.

Although from its economy of fuel, combined with high mechanical power, the Cornish pumping-engine has attracted considerable attention, one point in connection with the subject has hitherto been but imperfectly determined.

The heat developed from any fuel during its combustion is dependent mainly upon the carbon that it contains. The conversion of the whole of that carbon into carbonic acid is the result of perfect combustion, and this requires that two equivalents of oxygen should be obtained from the air for every equivalent of carbon in the fireplace. Each atom of carbon thus made to combine represents a fixed mechanical value; consequently, a theoretically perfect arrangement would be one in which all the carbon could be converted into carbonic acid, and in which the air supplied gives precisely the required quantity of oxygen. The caloric due to the combustion of the hydrogen is, in the case of coal, so small in relation to its other constituents as to be of comparatively little moment in the calculation.

It becomes consequently an interesting problem to determine, with as much accuracy as possible, the quantity of air supplied to the fireplaces of Cornish boilers. It may appear easy to ascertain with tolerable correctness the quantity of air passing through fireplaces constructed as those of the boilers of the Cornish steam-engines are.

If the temperature of the air had been uniform throughout the whole length of the flues, *i.e.* from its first entrance into the fireplace, to its exit from the top of the chimney, its ascensional force might be calculated from the difference between the weights of the heated column, and a column of air of the same height at the observed temperature of the atmosphere; and thus the quantity of air passing the fireplaces in a given time might be readily ascertained. This uniformity of temperature does not, however, exist, which is alone sufficient to render all calculations on the subject exceedingly intricate.

The alterations in temperature in different parts of the flues, and in the stacks of some Cornish engines, which were determined with much care, together with the differences in the temperature of the external air, will at once show how complicated this question is.

	Fah.
On the 29th June, at Tresavean mines, the thermometer stood at	72°
The coaling place of the large engine, 12 feet from the fire	87°
At 2 feet from the fire	90°
One foot from the ash-pit	110°
In the flue, 30 feet from the fire	330°
At the end of the flues, 101 feet from the fire	190°
On the 13th September, at North Roskear mine, the temperature of the air in the flue nearest the fireplace was	340°
At the bottom of the stack, 122 feet from the fireplace	234°

These results show that a large amount of calorific absorption is going on during the passage of the gaseous current through the flues and chimney.

Proceeding with this inquiry, it was resolved, in the first place, to deter-

mine, with precision, the distance through which the air had to travel from its leaving the fireplace to its quitting the stack.

The following are the measurements obtained at three of the most important engines in Cornwall:—

THE NEW ENGINE AT TRESAVEAN.

From the fire-door to the end of the flues . . .	101 feet.
Length of stack flue	40 „
Height of stack	60 „
	201

TAYLOR'S ENGINE, UNITED MINES.

From the fire-door to the end of flues	107 feet.
Height of stack	80 „
	187

WEST'S ENGINE, NORTH ROSKEAR.

Tube of boiler	37 feet.
Flues	72 „
Between ends of boilers and stack	12 „
Stack	90 „
	211

The author was enabled to determine with precision the volume of air in the flues, and the chimney, at North Roskear mine, and from similar data the capacity in each case was deduced.

Flues through tube, allowing for fire-bridge = 432 feet; for three boilers, say	1,296 cubic feet.
Flue over one boiler = 199 feet, three of them, say . .	597
Flue under one boiler = 567 feet, three of them, say . .	1,701
	3,594
Between boiler and stack	45
Ditto to damper .	45
Stack . . .	607
	4,291

Hence we approximate very nearly to the truth, when we consider the space occupied by the air, as being 4,291 cubic feet; which at 60° Fah. and the barometer at 30 inches, would be equal to say 328 lbs. avoirdupois. This requires correction for the expansion due to the elevated temperature of the flues. Without going into the details of this correction, it may be sufficient to state that it was determined that 238 lbs. of air were contained in the flues and chimneys at North Roskear mine.

It must not be forgotten that the gases and vapours from the coal which pass off unconsumed, form a portion of this amount. Somewhat more than 800 lbs. of coal are burnt in each boiler in 24 hours, by the combustion of which carbonic acid and water are formed; hence the flues and chimney contained nitrogen, carbonic acid, and watery vapour, together with uncombined oxygen.

The rate at which the air traverses the flues was determined by placing, immediately in front of the fire, some tow saturated with oil of turpentine, and closing the fire-door rapidly after it was thrown in. The dense black smoke generated in this way being seen at the top of the stack, gave, after numerous experiments, the following mean results:—

Tresavean.		North Roskear.		United Mines.	
M.	S.	M.	S.	M.	S.
1	50	2	00	1	40
1	55	2	24	1	55
2	00	2	10	1	52
1	52	2	3	2	00

The gaseous products formed by the combustion of the coals may be estimated* at 15 cubic feet per minute; this must be deducted from the contents, together with some other allowances arising from various interruptions to the currents, &c. This will reduce the quantity of air to about 3,000 feet. At the mean pressure and temperature, this will be equal to about 110 lbs. of air passing through the flues per minute. This air, having passed the fire, should have been deprived of its oxygen. Analyses were therefore necessary to determine this point. The air was collected in a receiver from the stack by a hole made in the brickwork, and subsequently removed in stopper bottles, and analysed with as little delay as possible. The eudiometric process was employed. In all cases the carbonic acid was first absorbed by caustic potash, and averaged one-ninth the total volume operated upon.

	CO_2
Thirty cubic inches of air from the nearest flue of the engine, Tresavean, gave	3·01
Ditto from flue nearest stack, ditto . . .	3·00
Ditto (*a second experiment*) from nearest flue, ditto	2·98
Ditto from nearest flue, North Roskear, ditto .	3·20
Ditto ditto ditto .	3·07
Ditto from end flue, Taylor's United mines, ditto .	2·75

The proportion of oxygen to nitrogen in the atmosphere is about one-fifth, thus we learn the quantity which has entered into combination with carbon and hydrogen to form carbonic acid and watery vapour, to develop available heat.

A few experiments with charcoal will show that, after its combustion in a close vessel, the air still contains sufficient oxygen to support the combustion of sulphur, and consequently that it is not possible to deprive atmospheric air of all its oxygen, by ignited coal alone. This accounts for the oxygen found in the flues. The results obtained appear to indicate that the admission of atmospheric air has in these cases been so regulated as to produce the best practical effects. If a less quantity had been admitted the fires would not have burned freely; and if, on the contrary, a larger amount had entered, it would have exerted a cooling influence and diminished the duty in proportion to the coals consumed. Experience has shown Cornish engineers that the best duty is obtained when all apertures through which strong currents could find their way into the apparatus are closed, and just sufficient air admitted to support a moderate but not rapid combustion.

The enginemen of Cornwall observe a fixed rule in the management of their fires. When coal is first introduced they merely spread it over the surface of the fire, and never stir or stoke it except at the time of cleaning. They then shut down the damper to prevent the rush of cold air, which would have the effect of lowering the temperature of the steam in the boiler. Subsequently they turn the unconsumed fuel on one side, and after raking off the

clinkers turn the fuel back on the clean bars, in order to repeat the operation on the other side. The fire before cleaning is about 6 inches deep, and after cleaning about 3 inches.

It is important to have some useful rule for determining the strength of boilers. It is generally considered that the strength is in direct proportion to the thickness of the plates, and inversely as their diameters. Practice appears to have settled that the iron plates cannot be less than a quarter of an inch nor more than half an inch in thickness. The tensile strain of good malleable iron is estimated at 56,000 lbs. One-third of this is regarded as the *extreme* force which it should bear, or 18,000 lbs. Mr. John Darlington says: "From this sum it is necessary to make liberal deductions for difference in the quality of iron, and also for bringing the pressure within the limit of safety." The following numbers represent the strain per square inch of section reduced to meet the above condition:—

Common Yorkshire iron plates	2,500 lbs. per square inch.
Best " "	4,000 " "
Common Staffordshire "	3,000 " "
Best " "	5,000 " "

There are several questions which bear directly on the improvement of the steam-engine which may be mentioned, though they would occupy too much space to receive full consideration in this volume. These are superheated steam and the expansion of steam in superheating, the evaporation of *vesicular* water, the *spheroidal state* as described by Boutigny, and its influence in producing boiler explosions. For a full description of the present state of our knowledge of these conditions, the reader is referred to the treatises which have been published in connection with this important question.

In mine pumping-engines the most serious accidents often arise from the breaking of main rods, which naturally takes place during the time that the cylinder is taking steam. The piston being suddenly relieved of its load, considerable damage is the result; a sudden decrease of load on the engine from any cause whatever endangers its safety, and the spring beams must suffer if the engineman is not at his post. What the engineer would do to prevent such a result would be to throw up the equilibrium catch immediately the engine evinces a tendency to what is technically called "coming indoors" too fast; but the engineer cannot always be prepared for such emergencies, nor could he, if stationed at the handles, throw up the catch in time. Husband's safety governor is therefore designed to act simultaneously with the engine, and is thus described in reference to Fig. 175.

The plunger Z makes its up-stroke with the up-stroke of the engine, and draws its water through the valve R, forming part of the ordinary cataract cistern. The water so pumped is discharged into the same cistern through the regulating cock, D, which is adjusted by means of a rod (M) from the engine floor. If the engine increases its speed above the normal rate of working, from any cause whatever, the water is throttled in its discharge through the cock D, and a pressure is thus imposed upon the piston E, tending to raise it; as the piston E rises, the lever S comes in contact with the

catch Q, and thereby lifts the equilibrium catch B; to increase the effectiveness, an additional cock (N) is provided, which closes as the piston E rises, thus increasing the force imposed on the said piston.

The importance of this arrangement will be obvious to any one acquainted with the steam-engine, and its value in meeting the necessities of the case is its strong recommendation. Before closing this brief description of the steam machines used in the drainage of mines, some notice must be given of their use for other mining purposes, and especially for the winding-engine and for the "Man-Engine" employed for raising and lowering the miners.

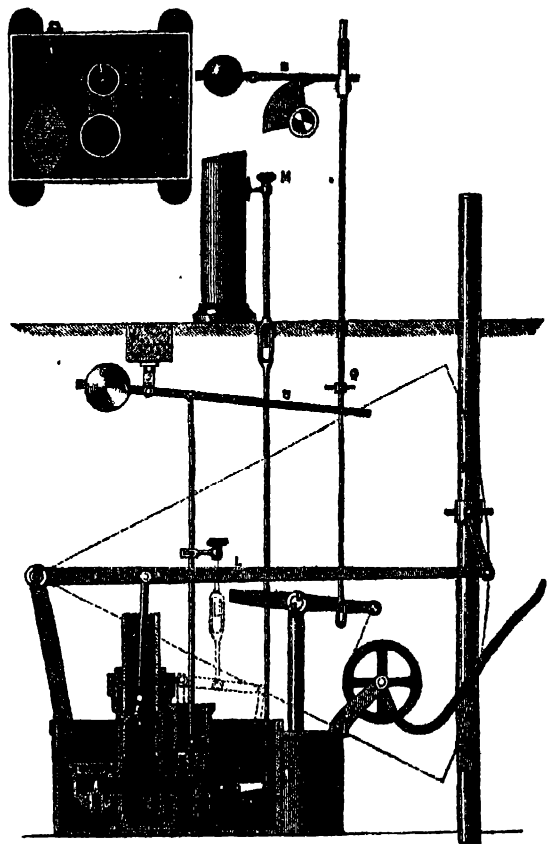

Fig. 175.

By the substitution of the steam winding-engine for the horse-whim, a considerable economy has been effected. The machinery of a winding-engine in Cornwall is generally more costly than that which is used in the colliery districts, but they wind more slowly, and the weight lifted is generally considerably less. The difference in expense between steam and horse whims has been estimated, by Mr. Joseph Carne, to exceed 50 per cent. in favour of the former. Most of the engines used for winding in Cornwall have been designed with a view of economising fuel, but it is questionable, when this result is obtained, whether the final result is so satisfactory.

A machine of this kind should not only be cheap in construction, but it should be simple in its action, have every facility for the regulation of speed, and possess the high merit of durability. Horizontal cages are frequently preferred to vertical ones, and in the colliery districts they adopt winding directly from the fly-wheel shaft, rather than placing the rope on a drum set in motion by toothed gearing. When the former method is used, a steam drag is connected with the fly-wheel, which the engine-driver brings into operation as may be required.

The following particulars show the prevailing conditions of the winding-engines of Cornwall and of North Wales :—

Character of Engine.	Average of Mines in Cornwall.	Minera Lead Mine, North Wales.	
	Vertical Condensing.	No. 1. Horizontal Spur Gear.	No. 2. Horizontal Spur Gear.
Diameter of cylinder	22 inches	14½ inches	14½ inches
Length of stroke	5 feet	3 feet	3 feet
Number of revolutions per minute .	15 to 20	50	50
Speed of piston in feet per minute .	150 to 200 feet	300 feet	380 feet
Pressure of steam on piston per square inch	12 lbs.	14 lbs.	15 lbs.
Mean diameter of drums . . .	4½	5	4½
Speed of rope in shaft per minute . .	150 feet	250 feet	250 feet
Weight of load drawn	10 cwt.	26 cwt.	25 cwt.
Tons drawn per day of 8 hours . .	—	100	100
Depth of shaft	variable	{120, 150, 170}	100
Diameter of drawing pulley . . .	5	7	4½

REMARKS:—No. 1, winding from one shaft; No. 2, 2·00 tons, if from two shafts.

TABLE SHOWING THE DUTY PERFORMED BY SOME OF THE BEST CORNISH WINDING ENGINES, FROM THE YEARS 1848 TO 1858.

(*From "Brown's Cornish Engine Monthly Reporter."*)

Year.	Mine.	Engines and their Power.		No. of Kibbles drawn.	Average Depth.	Average Weight of a Kibble of Stuff	Average Number of Kibbles drawn by consuming 1 cwt. of Coal.	Pounds raised 1 Foot high by consuming 1 cwt. of Coal.
			H.P.		Fms.	Lbs.		Millns.
1848	Fowey Consols .	22-in. double	29	5,300	246·8	1,000	19·8	29·3
	Par Consols .	24-in. and 13-in. combined	17	5,387	101·4	1,008	37·7	23·1
	Callington Mines	22-in. double . . .	29	5,203	111·5	1,008	26·0	17·5
	Great Polgooth .	22-in. double . . .	29	5,198	130·5	700	15·0	11·0
1850	Fowey Consols .	22-in. double . . .	29	5,798	255·1	1,000	18·3	28·0
	Great Polgooth .	22-in. double . . .	29	4,919	110·5	1,500	18·1	22·0
	Trelawny . .	24-in. and 14-in. combined	34	5,321	83·2	900	21·5	17·6
	Callington . .	18-in. double . . .	19	3,472	113·5	1,008	16·2	11·1
1852	Fowey Consols .	22-in. double . . .	29	5,775	257·0	1,000	19·4	29·9
	Great Polgooth .	22-in. double . . .	29	3,291	120·9	1,008	10·1	20·4
	Par Consols .	24-in. single . . .	27	7,729	89·5	1,008	40·5	23·7
	Devon Great Consols	30-in. and 16-in. combined	52	5,231	96·5	1,456	19·1	18·7
1854	Fowey Consols .	22-in. double . . .	29	4,133	255·6	1,000	19·4	29·8
	Fowey Consols .	18-in. double . . .	19	2,979	175·6	850	21·6	19·3
	Great Polgooth .	22-in. double . . .	29	3,043	162·7	1,008	10·1	18·0
	Par Consols .	24-in. single . . .	27	5,556	97·4	1,008	30·4	19·8
1856	Fowey Consols .	22-in. double . . .	29	4,513	236·7	1,000	20·3	28·8
	Par Consols .	24-in. and 13-in. combined	33	2,785	117·9	1,008	33·2	23·7
	Great Polgooth .	22-in. double . . .	29	3,838	147·9	1,008	10·7	16·3
	South Caradon .	30-in. and 16-in. combined	52	2,012	89·8	1,203	15·6	13·5
1858	Fowey Consols .	22-in. double . . .	29	5,887	233·1	1,000	17·5	24·5
	Par Consols .	24-in. single . . .	27	5,530	114·0	1,008	34·3	25·8
	Fowey Consols .	18-in. double . . .	19	2,632	143·8	850	18·3	13·4
	South Caradon .	30-in. and 16-in. combined	52	2,367	88·4	1,203	11·9	11·2

Another application of steam power has been made in the "*Man-Engine*," which has been employed in some of the mines to raise and lower the miners. A brief description of this labour-saving machine must be given. Mr. M. Loam, at a meeting of the Devon and Cornwall Miners' Association,

read a paper on its history, which supplies the information required. After referring to what had been done in the way of advancing steam-engines after Watt, until the duty of the Cornish engine was raised to a maximum of 80 millions, and reduced the cost of drainage two-thirds which led to a rapid and successful development of our mines, this rapid development involving great and increased physical strain through climbing upon the miners, which was felt to be a serious and increasing evil, he stated that so great was the exhaustion in the Consolidated mines, then one of the most important and deepest, that the older and experienced miners were unable to work in the deeper levels from sheer inability to climb from such depths, and young and inexperienced miners had to be employed in them. The Royal Cornwall Polytechnic Society took the matter up seriously, and pointed out the pernicious consequences of this climbing of the miners, besides exhausting, as it did in the Consolidated mines, one-third of the whole physical strength and work. The Society, through the liberality of Mr. Charles Fox, offered a premium in 1833 "for the best improvement on the present method of ascending and descending mines." It was under the medical, and not the physical aspects, that this subject was first brought under the late Mr. Loam's notice in 1827. The late Mr. J. Paul, then the leading surgeon in Gwennap, and one long esteemed in his profession, had watched the increase of pulmonary complaints among miners through climbing, and at one of the Consolidated mine meetings he called attention to it, said it was getting worse as the mines deepened, and suggested that their engineer should devise some means to supersede the ladders. Mr. Loam's first thought and suggestion was the obvious method of the collieries to raise the men with ropes, but the miners would not listen to being brought up like coal and rubbish; besides, the ropes might break and the men be killed, so that a better plan must be devised. It was this emphatic condemnation of the ropes that led Mr. Loam to discard them, and induced him subsequently to adopt the rod. In adopting the rod and fixed platforms instead of rope, it was found upon consideration that, apart from its assured safety, it was capable of greater facility and rapidity of discharge. With a rod 260 fathoms long, and conveying 130 men 2 fathoms apart, each travelling 10 fathoms per minute, it would equal 1,300 per man per minute with a single rod, and with two rods this rate would be doubled, and which no means of transit by rope could equal. The rod also enabled each miner to step on and off at any given point or level without stopping or interfering with the transit of others to their various levels. Mr. M. Loam well remembered his father's enthusiasm about this invention. It was the great topic of his thought and conversation, and the date of the invention must have been about the year 1829. It was hoped that the man-engine would have been adopted at the Consolidated mines, as they were then very rich and deep, but from some cause or other, the matter was deferred and ultimately dropped. But the action of the Polytechnic Society revived hopes, and Mr. Loam entered warmly into a contest for the premium offered, and was able to bring out his scheme in all its details. Mr. Paul was greatly pleased at Mr. Loam's success, and especially as the Polytechnic Society had approved of the model. But for some years after that there appeared no

prospect of its adoption. Although the society had for years offered premiums on its improvement, the mines failed to adopt it. At length Mr. Charles Fox and others offered a premium of £500, through the Society, to any Adventurers who would erect it. The late Rev. Canon Rogers also offered a premium of £50 to the engineer who should be the first to introduce an effective system for lowering and raising the miners. The first public trial was successfully made on the 5th of January, 1842, the man-engine, with two rods, as shown on Fig. 176, having been fixed to the depth of 27 fathoms. In the year 1841 negotiations were opened with one or two mines, but unexpected delays interfered, and no progress was made until the 23rd of December, when proposals came from Tresavean mine, engaging on their part to erect suitable machinery to the depth of 200 fathoms, on the condition of being paid £300 towards the first 100 fathoms, and £200 more on the completion of the second 100 fathoms. The society felt themselves justified in closing with this offer, and after the engine had been erected in 1842, and its success was an accomplished fact (its results were watched with keen interest by the society, and not less by the miners themselves), the premium of £500 was eventually paid to the Adventurers in Tresavean mine (the first portion of £300 being paid by the society when the first 100 fathoms was completed, and an additional £200 when the second 100 fathoms should have been successfully fixed), and also the premium of £50 to Mr. M. Loam, by the author of this volume, who was then secretary to the Royal Cornwall Polytechnic Society. Mr. Loam subsequently took a first prize for an improvement in the man-engine, and although others competed, their plans were not considered of such merit as to deserve a prize.

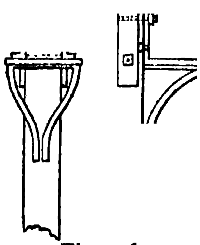

Fig. 176.

It has been carefully calculated that the cost of working the engine is not above one penny per man to the bottom of the mine. The miners at Tresavean mine joined in expressing their approbation of, and their thankfulness to the society for, the engine in unqualified terms.

In 1845 a second Man-Engine was started at the United mines, the same society paying £103 as a contribution towards the expense of erecting it. In 1851 a third engine was erected in Fowey Consols mine, under the direction of Mr. W. West, engineer, and Captain Puckey, agent. The construction of this machine differed in several respects from those which had been erected at Tresavean and the United mines. The plan had, however, been submitted to the judges at the Exhibition of the Polytechnic Society, and it was found to work extremely well.

Similar Man-Engines have been constructed at Dolcoath mine, and also at the Devon Great Consols, near Tavistock.

It will be easily understood that the two rods, with the platforms, fixed at regular distances, as shown in Fig. 176 above, moving alternately, will admit of a miner ascending or descending if the rod moves with a 10-feet

stroke—over 10 feet at each stroke of the engine. He steps, when the platforms come together—which they do when the crank is passing over the dead-point of its motion, and consequently when there is a brief rest—from the platform on which he stands to the other; the rod then begins to make its upward movement, and he is carried up another 10 feet. Thus without any fatigue he is lifted to the surface or carried to the bottom. Single rods (Fig. 177) are more frequently used; then the platforms are fixed to the side of the shaft. The miner is represented as stepping from the fixed platform to that which is about to ascend, and he is carried up 10 feet, when he steps off on to the fixed rest, and remains on it until the platform on the rod, 10 feet above that which he has left, has come down, and rests opposite to the one on which he stands, he then steps off, and is carried up another 10 feet. The rate of the machine with one rod is of course slower than that of the machine with two rods.

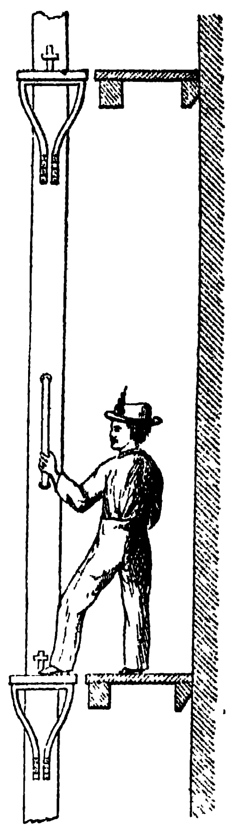

Fig. 177.

We shall have occasion to notice on a future page the influence on the health of the miners of climbing from great depths. It has been shown that the disease known as "miners' consumption" is largely due to this cause. The Man-Engine, therefore, as a means for removing the injurious influence, must be regarded as a great blessing, and it is to be regretted that it is not more generally applied. This is mainly due to the unfortunate system under which the mines of Cornwall and Devon are worked—a system which does not encourage the holder of shares to take any special interest in the mines themselves, his interest being confined to the market value of the shares which he holds.

MINING TOOLS.—In the chapters devoted to the boring of rock and to the dressing of ores several of the tools employed have been already described. There yet remain, however, tools which are important to the practical miner, and which demand attention. It will be more consistent with the purposes of this volume to deal with the *principles* involved in the construction, than to enter into any directions as to the use of tools.*

Borers.—In writing of rock-boring by machinery, a short space has been devoted to the consideration of tools or bits which have been employed, and a woodcut (Fig. 115) is given of five descriptions of bits. At one time the cutting ends of all borers were of hardened iron, but now they are always made of steel. Shear steel is generally employed for the bit, and this or blister steel is welded in a split weld to a bar of iron. Striking borers of the above class have been since 1851 superseded by such as are made entirely of cast steel, which has been drawn under the tilt-hammer into octagonal bars,

* Those readers who desire for practical purposes to make a selection of the tools required for mining operations and for the dressing of ores, or who are anxious to know kinds of metal best suited for special purposes, should consult the "Manual of Mining Tools, comprising Observations on the Materials from and Processes by which they are manufactured, their special Uses, Applications, Qualities, and Efficiency," by William Morgans, which is accompanied by an "Atlas of Mining Tools." Crosby Lockwood and Co. 1871.

and is familiarly known in the market as "borer steel." Steel possessing more tenacity than iron, admits of being made into borers which are lighter than those made of iron. A bar of steel being stiffer than an iron one, it will transmit with greater effectiveness a hammer blow than an iron bar will do. When the blow of a hammer is delivered upon a bar of metal a certain amount of *inertia* has to be overcome, that being determined by the quantity of matter between the end receiving the blow and the end in the bore-hole from which the effect is derived. The quantity of matter in a steel borer being less than that contained in an iron one of the same length, it will convey the force more effectively. On this principle a short borer is found to exert more power than a long one.

The bit of a borer is formed by flattening the end of the bar until about a quarter of an inch thick, and a little wider than the diameter of the hole which is to be bored. When used in boring hard ground, the face is best formed by tapping it with a light hammer, and then by carefully using a file. By hammering in the corners of a bit, the splay should be preserved to the extremity. This is done by properly inclining the face of the hammer, which can only be learnt by experience. The tempering of borers is important, and demands considerable attention. The cutting end, about 4 inches, previously sharpened, is heated to cherry redness in a clear fire; it is then immersed in cold water, as free from saline matter in solution as it can be obtained, to the depth of $\frac{3}{4}$ of an inch. The steel or iron of the bit is thus thoroughly chilled or hardened. The whole of the hot portion of the bar should then be plunged into the water for a short time and afterwards withdrawn. The colour of the steel in the process of tempering varies from straw-yellow to purple. Shades of brown produce a good temper and are favourites with many smiths. Heating the steel to the exact temperature should be carefully secured, and the knowledge of this is obtainable only by carefully observing the results of continued practice.

The pulverised matter formed in boring has to be removed from the hole, and for this purpose "scrapers" are used. They are usually made of light iron rod of from $\frac{1}{4}$ inch to $\frac{1}{2}$ inch thick, sufficiently long to reach the bottom of the hole, the scraping end flattened out to the diameter of the hole with a ledge for receiving the "boring *dust*" or "*meal*" (or when damped "*sludge*"). "Drags" and "spoons" are also used for a similar purpose. For clearing the bore-hole the "*swab-stick*" is employed. This is a piece of stick small enough to enter the hole and long enough to reach the bottom. The fibre at one end of the stick is spread out by bruising the wood. When this is put into the hole the "sludge" passes into the fibrous brush, and can be brought up. In a few operations the hole is cleaned. "*Clay irons*" are used for forcing clay into the joints in watery holes, and to make them dry for using naked powder. This is simply a bar of iron a little smaller than the bore-hole, with a broad top for striking upon. The wet hole is charged with tough clay, and the clay iron is driven through it by a sledge, forcing the clay into all the crevices, so that entrance of water is stopped. Frequently the entrance of water is thus stopped, but it sometimes fails.

The "*shooting-needle*" or "nail" is used for forcing a passage through

the tamping which confines the charge. The introduction of the safety-fuse for blasting has nearly superseded this process. The "safety-fuse" is generally made of tape, but often of hemp yarn, guttapercha, or metallic foil. This is wound up so as to form a small tube, into which is poured a continuous core of fine powder or priming. A piece of the safety-fuse is put into the hole, one end penetrating the charge of gunpowder instead of the needle, and the tamping is rammed in afterwards. The outside end is ignited, and the fuse becomes a slow train, burning at the rate of about 2 feet per minute, and it can be cut off sufficiently long for the miner to retire into security after igniting it. The method of blasting by electricity has been already explained.

Tamping has been named. This requires the use of a bar of metal to force the material used into a firm coherent mass above the powder. The tamping bars are usually of iron or steel; but many accidents have arisen from their use. Copper rods have been employed with bronze facings, to avoid the danger of producing a spark by driving iron against a silicious rock or fragment. Mr. R. W. Fox introduced a wedge for avoiding the use of tamping. It was very simply made. A branch of a tree, of a diameter slightly less than that of the hole, is cut into three wedge-shaped pieces 1, 2, 3, by two cuts of a saw, and a hole drilled through the central piece from *a*, Fig. 178. To use this the middle piece is dropped into the hole upon the powder, and the safety-fuse passed down to the powder; the side wedges 1 and 2 are then placed in their correct position and pressed down. No other tamping is required. The gunpowder exploding exerts an enormous force on the wedge 3, and the pressure on the rock becomes very great, the two wedges 1 and 2 resisting the action of the central wedge.

Beating the borer is generally effected by two men, one of them holding and moving the borer in the hole, and the other regularly delivering the blow. Sometimes the operation is carried out by one man, who delivers the blow with his right hand and moves the borer with his left one, but this is heavy and very trying labour.

The force of the blow for effecting the most advantageous result varies with the nature of the ground. In dense sharp rock the borer will not bear such heavy beating as in strata of a tougher kind, such as Killas (Clay-Slate) or hornblendic Slate. Intelligent miners by experience learn the kind of blow which is most desirable, and they regulate the strength of the blow to the description of "country" they are working in.

Much depends on the turning of the borer, which requires some dexterity to ensure that the holes be kept round and true. The duration of a bit varies considerably in the hands of different miners. In hard ground some steel borers will do good service at the cutting end, but stand indifferently under the blows at the striking end. The wear of various kinds of steel should be noted, and that selected which gives after trials the best result. Sometimes steel thimbles are driven on to the borers at the striking end to prevent the wear from the beating. Inferior steel is always disadvantageous, and consequently attended by loss. The best steel carefully

sharpened and tempered will be found to be always in the long run the most economical.

Bits vary considerably, according to the character of the rock upon which they are to be employed. It would not be satisfactory to describe the varied forms of the cutting edges of borers without drawings of them, and even then the miner or the smith would scarcely be guided satisfactorily. Experience gained by carefully noting the results obtained under different conditions is the only reliable guide for the miner.

Hammers and Sledges.—When a tool of this kind is furnished with a metal head and is intended to be used with one hand it is called a *hammer*. When it is to be used with both hands it is named a *sledge*. (Wooden-headed tools are commonly called sledges, and sometimes *mallets.*)

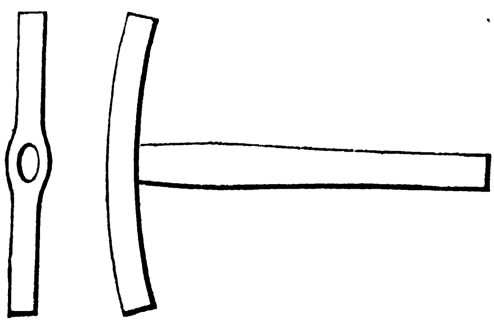

Fig. 179.

Hammers scarcely require description, the varieties are so generally well known. They vary in shape in different localities. In the St. Just mining district the miners are very expert in single-hand boring, and they use a hammer with a long bloat-head with a little sweep, Fig. 179. In another part of Cornwall they use what are called "cat's-head" hammers; these have short, broad, bully heads, with the panes sharply chamfered down to the size of a halfpenny. This shape secures the miner turning the borer from a blow if the hammer glances aside. This tool is shown on Fig. 180.

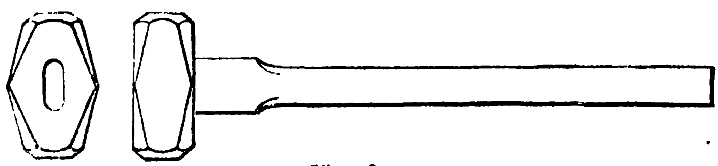

Fig. 180.

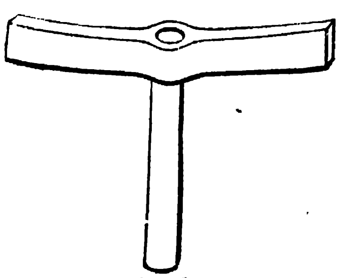

Fig. 181.

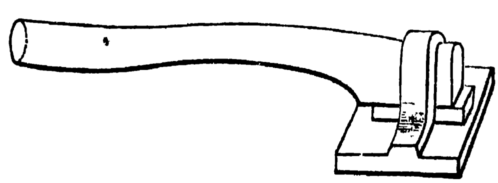

Fig. 182.

The boring mallet has a head usually made of a block of elm.

Single-hand boring hammers weigh from 2½ lbs. to 4 lbs.

Sledges for double-hand boring weigh from 4 lbs. to 10 lbs.

The handles of boring hammers are from 6 inches to 18 inches long.

The handles of boring sledges are from 18 inches to 30 inches.

Sledges are frequently used for breaking up lumps, and for this purpose

"lump-sledges" are used, the weight of the head varying from 10 lbs. to 20 lbs.

In the dressing of ores various hammers are employed. The "cobbing hammer" is shaped as in Fig. 181, the head varying from 14 to 18 inches long and weighing from 2 lbs. to 4 lbs.

The "bucking hammer" (Fig. 182) or "Iron" is a striking plate of iron, with a stirrup to receive the handle, which is secured by a wooden wedge driven in the back of the plate. Rollers and crushing machinery are gradually superseding these hammers.

Picks.—These are instruments which are essentially the miner's tools. They are of great antiquity, being represented on the Egyptian and Assyrian monuments, found in the grave-mounds of the earliest races who inhabited Europe, and in the mines worked by the Romans. They pass by different names in various districts, as "pikes," "slitters," "mattocks," "hacks," and "mandrels."

The pick-head is usually of wrought iron with steel tips. An eye is formed in its centre to receive the handle or *helve*, which is generally secured by a wedge.

The action of a pick is to penetrate, chip, or break up by rending the mineral substance upon which it is used. Picks are used with advantage in working jointed, shaly, or fissured rock. The force of the blow, which is regulated by the blow urged by the miner, expends itself in making the point of the pick penetrate the ground, and thus loosen it. It is also of value as a bent lever. When it has entered the ground the pick forms its own fulcrum and acts like a crow-bar. It thus affords the most convenient tool

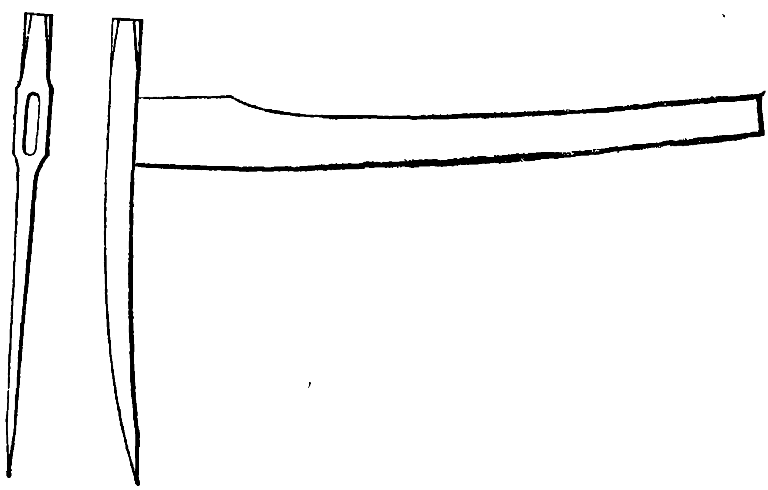

Fig. 183.

for levering the ground. It is also employed as a *scraper* for dragging out the stuff loosened by working, Fig. 183. The weights of picks vary in different districts, and the shape is determined by the nature of the material upon which it is to be employed. The picks used in metal mines and those employed in collieries differ considerably. The "poll-pick" is much used in Cornwall, in Derbyshire, in Flintshire, and other mining districts. It differs from ordinary picks which have two stems, by having one

about 12 inches long and a stump, forming the "poll," about 3 inches long. The face of the poll is steeled like a hammer, so that it can be used for striking blows. The length of the handle or "helve" is generally from 26 to 28 inches; it is slightly curved and feathered on one side only.

The poll-pick can be used both as a pick and a sledge. It is sometimes used as a wedge, and by carefully striking it on the poll end it does this effectively, but if the poll is struck too heavily the eye of the pick is liable to burst. If the pick is used too severely it is liable to "wince"—that is, to alter the adjustment of the handle. The mischief of "wincing" can be avoided to a great extent by increasing the end-bearing surface of the eye. In some cases corbel bits are welded at the ends of the eye. To avoid this the ends of the eye should be made as deep as possible in the direction of the helve, in order to give the feather, when prizing, fulcrum as far as possible from the neutral axis of the head.

Shovels, Spades.—In the historical sketch some illustrations have been given of the shovels used by the ancient miners. They are, therefore, of very high antiquity. Without the shovel the earth mounds could not have been formed, nor the earthworks of old fortifications constructed. The principle of the ordinary shovel is that the plate shall be of iron, with steel around the front edges, or "mouth." It is furnished with two "straps," or "ears," to receive the helve, which should be made of ash. The plate is a little dished; it is slightly concave on the top surface, which is caused by the sloping of the back and sides, by which firmness is secured, and the plate sustains its load more securely. The long-handled shovel is used in Devon and Cornwall; in most other districts the shorter handle is furnished with a crutch.

The *Vanning shovel* of the tin-miner, to be effective, should be carefully made. The plate is generally larger than the gravel shovel; and as it is not used for any heavy work it need not be so thick, and is consequently lighter. The curved surface of the dish should be nicely adjusted to insure the separation of the "edge of tin" from the coarser stuff, which is to be washed away.

There are many tools employed in the process of mining which do not require description in this volume. In the process of timbering the shafts or the levels, hatchets, axes, and adzes are used, and saws of various kinds; but these belong to the engineering department or to the carpenter, and have no especial peculiarity as mining implements.

There are a few tools which are still used by the old miners, but which are gradually being superseded by the more modern arrangements, which must be named. For example, "*gads*." These are made of wrought-iron; when they have a point they are termed *gads*, when made with a chisel edge they are *wedges*. These vary much in size, the length being from 3 inches to 2 feet, but as a general rule they are from 6 inches to 1 foot. Frequently a tongue of steel is welded in to the iron to form a point, and often the striking end is faced with steel. By far the best arrangement is to make the gad entirely of steel. The "*Saxon gad*" has an eye near the middle, so that a number can be placed on a rope by the miner when proceeding to his work. Gads are much used in working "*vuggy*" or hollow ground, and on such rocks as are jointed. For this purpose such as are made of shear steel should be employed.

Wedges are more extensively used in collieries than in metal-mines. An

arrangement called "*plug and feathers*" is sometimes employed for breaking out large blocks of mineral ore. For this, a hole is bored, and two inverted wedges with circular backs are placed in the hole, then a driving wedge or plug is driven in between them to break out the mass. The wedges and gads being often lost, through neglect on the part of the miner, who should search them out of the broken material in which they are often buried, it is now a common practice to charge the miner for the steel which is lost.

"*Pickers*" and "*pokers*," which are made of ⅞-inch round iron with steel tops, are used for working in jointed ground and in thin veins. For clearing clay joints they are very important, and in St. Just, where thin veins of tin are very common, these tools are much used. The miners of St. Just use the pickers very dexterously, and they can often be distinguished from other miners by a horny mark on the back of the little finger on the left hand, which is caused by holding it under the haft of the picker for keeping up the point. These tools are held by the miners in one hand, and struck by a hammer with the other.

The "*set*" or "*moil*" is used for cutting ground where it requires to be done evenly, as in cutting "*hitches*" or preparing "*sealings*" for pit-work or the like. The "set" is shaped like a poker, and when intended for single-hand use, they weigh about 4 lbs. In many cases they are made much heavier, and then they are called "*double-hand sets*," and in many respects resemble borers. Bars—as "*socket bars*," or "*beche*," "crow bars," and "pinch bars"—are useful for levering out ground, and for splitting rocks traversed by cleavage planes.

Especial attention should in every case be given to the quality of the iron or steel which is employed in mining implements, and of the wood which is used to form the handles of picks, shovels, and other mining tools. It is always the truest economy to employ the most perfect metal and the best selected pieces of ash for the handles and helves of shovels and picks.

MINE SURVEYING.—A thorough familiarity with the principles of underground surveying is of the utmost value in the education of a miner. It may appear to many that he has but to sink a hole from the surface down to the mineral lode, and then to break out the ore, following the lode wherever it may lead him. Without doubt this was, in the early days of mining, the practice of the untaught man, who could only sink his shaft a few fathoms in depth, and drive his level for but short distances, by reason of the gathering of water in the shallow workings. Experience taught the miner the advantage of adopting some principle which would enable him, having sunk a vertical shaft on the side of a hill, to cut from the bottom of the hill, a level, or adit, which should reach the deepest point of the shaft, and thus drain all above that point of the accumulated waters. It was an ancient practice to mark out upon the surface the line from the mouth of the shaft to the lowest ground. This guided the miner in cutting the level through which the water should flow.

As mining operations became more and more complicated by the extension of the levels, and especially by the driving of levels at different depths upon the lode—which levels were connected by winzes—the necessity for a careful survey increased.

The most reliable guide to the surveyor is the compass-needle—a bar of iron or steel rendered magnetic—possessing the property—when suspended being free to move—of placing itself in a constant direction. One end of this bar always points towards what we term the north pole of the Earth, and the other to its south pole. The magnetic bar furnishes the means of determining, under all the usual conditions, a fixed line, from which the positions of any other line can be readily determined. This electrical bar is called the magnetic-needle, and when it is fixed on a delicate pivot upon which it is free to move, beneath which is a circular card divided into 360 degrees, we have the surveyors' or the mariners' compass.

The graduated card of this instrument is divided into the four cardinal points—North, South, East, West. The two first—north and south—are the line where the meridian cuts the horizon. The points of the line east and west are each 90° distant from the points north and south, therefore the circle is divided into four equal parts of 90° each.

The magnetic force manifests itself, on the surface of our globe, by three classes of phenomena. The *declination* of the magnetised bar, its *inclination*, and the *intensity* with which the terrestrial force acts on the needle. The *declination* is the angle that is formed with the direction of the meridian of the plane by the direction of a magnetised needle placed upon a vertical point or suspended by a thread, free of torsion, in such a manner that it holds itself horizontal.

The *inclination* is the angle formed with the horizon in the magnetic meridian by the direction of a magnetised needle sustained by its centre of gravity, around which it is able to turn in a vertical plane. These three elements—declination, inclination, and intensity—vary, not only from one place to another, but in the same place with time. The point of the needle which is directed towards the north has been termed the *north pole*, and that which is directed to the south the *south pole*. The direction of the magnetic-needle is so constant that even when the needle is drawn aside it always returns to its original position, and it is always the same extremity of the needle which is turned towards the north. The direction of the magnetic-needle is constant for the *same place* and for a *given epoch*. It is also subject, on the same point of the globe, to small periodic variations during the day, which have been termed *diurnal variations*.

The direction is not exactly north and south. The plane that passes through the centre of the Earth in the direction of the magnetic-needle, in any place under consideration, is termed the *magnetic meridian*, to distinguish it from the *terrestrial meridian*, which is the plane passing through the same place and the axis of the earth.

The angle made by these two planes is termed the declination of the magnet. The declination is east and west of the terrestrial meridian. The difference between the magnetic and the true meridian at different periods in London has been as follows :—

In 1576 it was	11° 15' to the east.	
From 1657 to 1662	0	
In 1670	2° 6' to the west.	
In 1815	24° 2' 18" ,,	(maximum direction.)
In 1849	22° 35' ,,	
In 1883 it is	18° 15' ,,	

It is necessary in all mining surveys to note the variation of the needle at the time the survey is made. The lines on a mining plan which indicate the direction of the workings in 1883 will, unless they have been corrected,—in twenty years,—deviate considerably from the lines drawn.

To determine the variation, a magnetic-needle, delicately suspended, is used. A carefully divided circle, upon which is read the division corresponding with the extremities of the needle, is fixed against the sides of a circular box of copper and covered with glass, in which box the needle, resting on its point, is placed. Delicate instruments are furnished with a telescope carried on an axis of rotation, parallel to the plane of the circular division, and the middle of which is upon the vertical that passes through the centre of suspension of the needle. The axis carries an air-level and a vertical quadrant divided to measure the angles described by the telescope. The box is turned round upon a vertical axis, by which it is fixed upon its stand, until the telescope is found to be placed in the direction of the meridian. The angle made by the direction of the telescope with the direction of the magnetic-needle is then determined, and we obtain the declination. If we know the declination (which is regularly published in the "Nautical Almanack," as determined by the Astronomer-Royal and copied into most other almanacks) we turn the box until the angle made by the axis of the telescope and the direction of the needle are equal to it, then we have the position of the meridian.

With the *inclination* or *dip* of the needle the miner has little to do, and the magnetic bar in the miner's compass is so adjusted as to be independent of the Earth's attractive magnetic power.

The force which we call *magnetism* appears to have been discovered at an early period in Greece. The name is supposed to have been derived from the province of Magnesia, in which a stone (*magnetic iron ore*) was first found by a shepherd. It is said by the Chinese that they used the magnet in the year 121 of the Christian era. Another Chinese authority tells us that under the dynasty of Tsin, 419 years before Christ, vessels were directed towards the south by means of the magnet. Vasco de Gama appears to have employed the magnet in his first expedition to India. The discovery of the declination of the needle was made by Christopher Columbus: the change of declination, in the same place, was discovered by Gunter, a professor in Gresham College; and the *dip* was first observed by Normann in 1576.

With this introduction we proceed to describe the processes of subterranean surveying.

Amongst the instruments used the *circumferentor* is important. It consists of an horizontal circular plate with a graduated circle of degrees numbered from 0° to 360°, and a *vernier*, by which these primary divisions are subdivided to single minutes. The *Theodolite* is a delicate instrument of much value for measuring angles, and *Gunter's chain* is a simple measure of length, which is used in coal mines: it contains 100 links. A chain is now used in the metal mines of Derbyshire and Cornwall which is divided into 100 feet.

It is essential that the mine surveyor should thoroughly understand and use the best instruments. The following are the most important:—

The Y level, in ordinary use, consists of a telescope resting upon two supporters, which are commonly from their shape called Y's. The lower ends of these supporters are let perpendicularly into a strong bar, which carries the compass-box. This compass-box is convenient for taking bearings, and has a contrivance for throwing the needle off its centre. One of the Y supporters is fitted into a socket, and can be raised or lowered by a screw. Beneath the compass-box is a conical axis passing through the upper of two parallel plates, and terminating in a ball supported in a socket. Immediately above this upper parallel plate is a collar, which by turning the clamping screw is made to embrace the conical axis. A slow horizontal motion may then be given to the instrument by means of a tangent screw. A spirit-level is fixed to the telescope by a joint at one end and a capstan-headed screw at the other, to raise or depress it for adjustment. The telescope embraces a large field of view, but the measurements required will only refer to one particular part, which is always the centre of the field of view. Some fixed point must be placed on the field of view at the focus of the eye-piece. Two fixed lines furnish such a point, and those are furnished by two spider's threads fixed at right angles to each other in the focus of the eye-piece. These are attached by some cement to a brass ring of smaller dimensions than the tube of the telescope, which can be fixed by means of four small screws.

The adjustment of the level will require close attention to rules, which the mine surveyor can obtain from several works devoted to this art.*

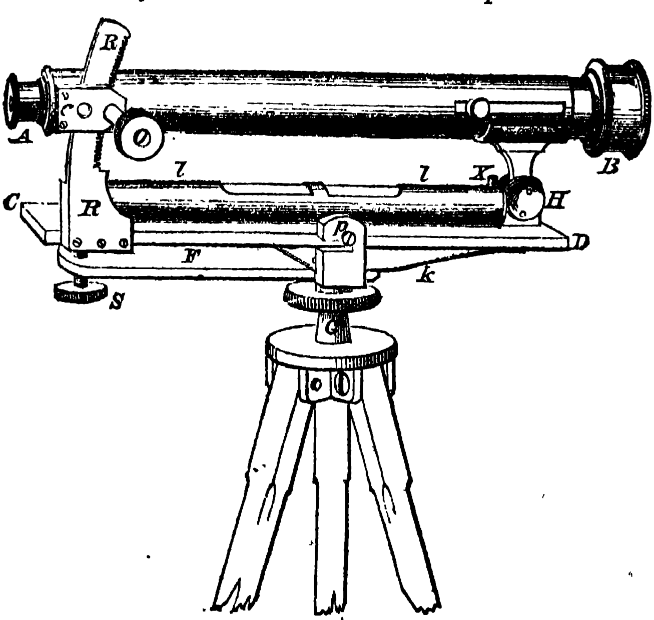

Fig. 184.

For mining operations, instruments adapted to measure the rise or fall of each 100 feet of distance are convenient.

The level represented (Fig. 184) is a particularly useful one. The telescope A B is attached at the object-end to the bar C D by the hinge-joint H, and this bar is attached to a second bar, F, by the spring *k* and the pivot *p*. The bar F screws on to an axis G, fitted to the head of a tripod stand, and the bar C D being approximately levelled by moving the legs of the stand, is brought truly horizontal by turning the screw S until the level comes to the centre of

* See especially J. F. Heather's "Mathematical Instruments." There is a small original edition and another enlarged edition in 3 vols. T. Baker, C.E., "Land and Engineering Surveying," and his "Subterraneous Surveying." Crosby Lockwood & Co.

its rim. The eye-end A of the telescope is attached to the bar C D by the arc R R, and is moved along this arc by means of a rack and pinion moved by the screw T. The arc R R is graduated to show the rise and fall in every 100 feet, and is read by means of an index seen through the small circular opening *c*. The bubble in the level is adjusted by the capstan-headed screw.

The Miners' Dial is an instrument especially adapted for subterranean surveying. It may be used as a plain theodolite at any station, without disturbing the work done by means of the compass-needle, or altering the form of entries in the levelling-book. This instrument has been the object of very great attention in Cornwall; and amongst others, Mr. Wilton, mathematical instrument maker, of St. Day, near Redruth, made many important improvements. *Wilton's Improved Miners' Dial* is so constructed that it may be used as a common dial,—as a theodolite without a vertical arc,—or a telescope, or a theodolite to which a telescope, and vertical arc, may be attached. This dial has been subjected to yet further and more recent improvements by Mr. Edward T. Newton, Mr. Wilton's son-in-law and successor, now of Camborne, Cornwall.

The Theodolite.—This instrument may be considered as consisting of three parts—the parallel plates, with adjusting screws fitting on to the staff-head, of exactly the same construction as already described, for supporting the Y and other levels; the horizontal limb, for measuring the horizontal angles; and the vertical limb, for measuring the vertical angles, or angles of elevation, Fig. 185.

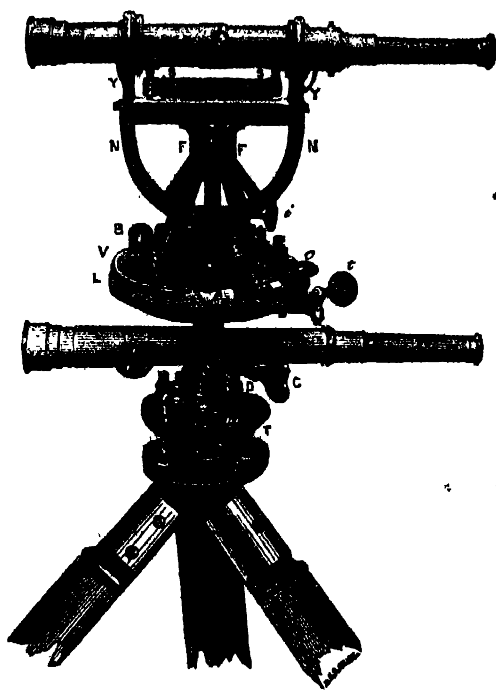

Fig. 185.

The horizontal limb is composed of two circular plates, I and V, which fit accurately one upon the other. The lower plate projects beyond the other, and its projecting edge is sloped off, or chamfered, as it is called, and graduated at every half-degree. The upper plate is called the vernier plate, and has portions of its edge chamfered off, so as to form with the chamfered edge of the lower plate continued portions of the same conical surface. These chamfered portions of the upper plate are graduated to form the verniers, by which the limb is subdivided to single minutes. The 6-inch theodolite represented in our figure has two such verniers 180° apart. The lower plate of the horizontal limb is attached to a conical axis passing through the upper parallel plate, and terminating in a ball fitting in a socket upon the lower parallel plate, exactly as the vertical axis of the Y level already described. This axis is, however, hollowed to receive a similar

conical axis ground accurately to fit it, so that the axes of the two cones may be exactly coincident or parallel. To the internal axis the upper or vernier plate of the horizontal limb is attached, and thus while the whole limb can be moved through any horizontal angle desired, the upper plate only can also be moved through any desired angle, when the lower plate is fixed by means of the clamping screw G, which tightens the collar D. T is a slow-motion screw, which moves the whole limb through a small space to adjust it more perfectly after tightening the collar D by the clamping screw C. There is also a clamping screw *c* for fixing the upper or vernier plate to the lower plate, and a tangent screw *t* for giving the vernier plate a slow motion upon the lower plate when so clamped. Two spirit levels B B are placed upon the horizontal limb at right angles to each other, and a compass G is also placed upon it in the centre between the supports F F for the vertical limb.

The vertical limb N N is divided upon one side, at every 30 minutes each way, from 0° to 90°, and subdivided by the vernier, which is fixed to the compass-box, to single minutes. Upon the other side are marked the number of links to be deducted from each chain for various angles of inclination, in order to reduce the distances as measured along ground, rising or falling at these angles, to the corresponding horizontal distances. The axis of this limb must rest in a position truly parallel to the horizontal limb upon the supports F F so as to be horizontal when the horizontal limb is set truly level, and the plane of the vertical limb should be accurately perpendicular to its axis. To the top of the limb N N is attached a bar, which carries two Y's for supporting a telescope of the same construction as that before described for the Y spirit level; and underneath the telescope is a spirit level S S attached to it at one end by a joint and at the other end by a capstan-headed screw, as in the Y level. The horizontal axis can be fixed by a clamping screw, and the vertical limb can then be moved through a small space by a slow-motion screw *i*.

Before commencing observations with this instrument, the following adjustments must be attended to:—

1. Adjustment of the telescope, viz. the adjustment for parallax; the adjustment for collimation.

2. Adjustment of the horizontal limb, viz. to set the levels on the horizontal limb to indicate the verticality of the azimuthal axis.

3. Adjustment of the vertical limb, viz. to set the level beneath the telescope to indicate the horizontality of the line of collimation.

Newton's Combined Miners' Dial—Theodolite—and Dumpy Level consists of a 6½-inch compass-box, the levels being inside. On the face of the dial are two verniers reading to minutes. The improvement in this dial consists of an arrangement by which the bearings are taken simultaneously with loose needle and vernier, the latter automatically checking the former; thus any error arising from incorrect reading or from local attraction is detected. The dial has a quadrant with a large and powerful telescope for surface surveying; the telescope being movable can be replaced by a pair of sights for underground surveys; the dial has also a pair of sights for dialling. On removing the quadrant from the dial the telescope can be put on the dial, it can then be used as a dumpy level. The quadrant is so constructed that the face of the dial is always clear for reading the needle and vernier. It is

graduated on one side into degrees and half-degrees vernier reading to minutes, on the other side into feet and inches.* An extra set of legs with candle reader also fits the dial; by its use it enables the dialler to take his bearings with greater dispatch and accuracy.

Instructions for commencing a Line of Survey with Newton's Dial, with Two Sets of Legs and Candle Reader.—Place the dial on its legs at first station; get the levels right by means of the ball and adjusting screws; see that the vernier on the face of the dial is clamped to 360°, then get the needle to read to 360°; then screw the dial tight on the legs with the socket screw; place the other set of legs in position at second station; get the levels on the candle reader right, then set the vernier free on the face of the dial by unscrewing the long clamp screw; move the dial round until the sight intersects the candle reader at second station; read angle by needle and vernier; then measure the distance. Clamp the vernier and take off the dial from the legs at first station, and fix it on legs at second station; with the candle reader on the legs at first station, take a back draft, then remove the legs from first station and fix them at third. The needle and vernier will read alike in any draft, unless there should be iron in the way; then the vernier at once checks the needle, and gives the proper bearing. The miner can go on with his survey as if using the common miner's dial, the vernier correcting any error in reading the needle—always remembering to take a back draft with vernier clamped at last angle.

Instructions to commence a Line of Survey where the Needle is rendered useless from the Vicinity of Iron.—Fix the dial on its stand and get it level at the second station, with vernier at 360°, and take a back observation, the other stand and candle reader being the object on first station. Screw the instrument tight on its stand, then measure the distance; this forms the first draft. Remove the stand with candle reader to third station, get it level, then take a fore observation by unscrewing the clamp screw of the vernier, which sets it free; then revolve the dial until it intersects the candle reader at third station, measure the line and enter this distance, also the angle now indicated by the vernier; place the dial on the legs at third station; loosen the dial on its legs so that the whole instrument shall revolve, with vernier clamped at last angle. Move the dial until it intersects the candle reader by back observation again. Take a fore observation by screwing the dial tight on its legs and unscrewing clamp screw of vernier, revolving the dial until it intersects the candle reader at fourth station; measure the distance and angle by vernier. In this manner any number of observations may be taken, always remembering to take a first back observation with the vernier at the angle last read. By this means the miner will be enabled to continue the work from the same meridian—that is, the zero of the instrument at the close of the survey will have the same direction that it had at the commencement. All angles thus taken on the number of degrees indicated by vernier should be entered as if taken by needle. The work may be laid down by protractor and scales as if surveyed by needle. If, however, it be desirable to ascertain the direction of the survey with regard to the magnetic meridian, this may be done as follows:—Having the angle as before, at any convenient station, the vernier at 360° and clamped there, set the needle free and direct

* See Appendix for Table showing the underlies and perpendicular to every degree of the quadrant.

the sight along the same line; enter the angle indicated by the needle: this will give the angle for the north as required. The work can be resumed by needle or vernier, and completed with either. From the bearing of the line thus obtained, the magnetic meridian may be set off on the plan by placing the protractor so that the angle taken by the needle may coincide with the angle of the same draft taken by vernier; then marking the position of the zero of the protractor, a straight line drawn through that point and the centre of the protractor will be the meridian. If, however, it be required to lay down the work on a plan in which the meridian is already determined with a protractor, the same graduations will do for both needle and vernier. Place the protractor on the meridian of the plan, with the 360° towards the north; mark the centre of the protractor and the degrees indicated by the needle at the given draft from the proper graduation for needle, remove the protractor and place it again on the same centre, with the angle taken by the vernier at the same station. The zero of the protractor will now bear the same relation to the meridian of the plan that the first line of survey did to the magnetic meridian, and that all the angles of the survey are taken from the first line as a meridian. They may now be marked off from the protractor in this position in the usual way.

Angles taken in the manner described may be reduced to angles from the north by the following rules—having the angle by vernier at any station, and the angle by needle at the same station:—

Rule I.—Subtract angle by vernier at any station from angle by needle at the same station; the difference is the angle of first draft from the north, but if the angle of vernier exceeds the angle taken by the needle, add 360° to the latter and subtract the angle by vernier. The remainder is the angle from the north. Add every subsequent angle by vernier to the angle by needle, as obtained above; the sum is the angle made by the corresponding draft with the north. If, however, such sum is greater than 360°, subtract that number from it; the remainder is the angle from the north as required.

Rule II.—If the last angle by vernier be less than the preceding angle add their difference to angle by needle; the sum will be the angle from the north; if such sum is greater than 360°, subtract that number from it; the remainder is the angle from the north.

If the last angle by vernier be greater than the preceding angle, subtract their difference from angle by needle; the remainder will be the angle from the north; but if the difference between the two angles be greater than the angle taken by the needle, add 360° to that angle and subtract the difference; the remainder will be the angle from the north.

This ingenious mathematical instrument maker has recently introduced a small portable dial and quadrant, which by its simplicity and portability strongly recommends itself to the intelligent miner.

This little instrument has 3-inch compass-box divided similar to a large dial, it has two levels at right angles, and folding sights. The quadrant is fixed under the dial in using the instrument. When fixed on the legs it revolves on a shank similar to a larger one; there is a clamp screw attached to the quadrant which by unscrewing a turn or two sets the quadrant free and enables the user to take the elevation or depression. On bringing the

quadrant back to zero, the needle of the dial at once gives the bearing. The legs are made to fold up, and when closed are just the size of a good walking-stick, and can be used as such. The instrument is complete in itself and is fitted into a nice mahogany case.

For subterranean work, the altitude or depression of any point may be ascertained by means of the theodolite attached to the circumferentor. This may also be used for surface levelling, either by taking the *angles* of elevation or depression or by fixing the quadrant at zero and using the instrument as a spirit level.

With the levelling instrument the altitude of any place is determined by fixing it at any convenient situation, to command a back sight to the staff at the commencement of the line of operation, and a fore sight to the next station. The difference between the staff readings will be the difference of the level of the two points.*

The Transit Instrument.—The transit instrument is a standard one in every astronomical observatory, where it is used to define a vertical circle passing from the north to the south point of the zenith of the place. It is equally useful to find any number of points in a straight line connecting two given points in mining or in land surveying.

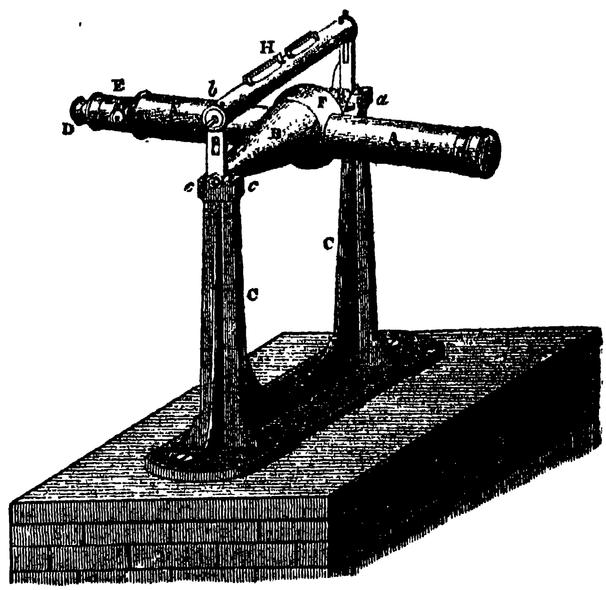

Fig. 186.

The line thus connecting the distant points is the base of a vertical plane of small extent. The telescope A A, Fig. 186, is made to revolve vertically upon an horizontal axis B B, the pivots of which are supported by the upright arms C C of the iron stand. The telescope resembles those of theodolites and spirit levels, and for mining or railway surveying purposes it is supplied with a system of cross wires. The intersection of the centre wires with each other represents, when in proper adjustment, the line of collimation or optical axis of the telescope. The slide D, or eye-piece, is movable in or out to obtain distinct vision of the cross wires; an adjustment that must be made or verified each time the instrument is set up for use. In adjusting the eye-piece to obtain distinct vision of the wires it will be found that it can be accomplished with greater certainty by directing the telescope to a white sheet of paper fastened at a little distance off. The screw E gives motion to

* For practical purposes the miner may consult J. Budge's "Practical Miner's Guide," Longman, Green, & Co.; Thomas Fenwick and Thomas Baker, "Subterraneous Surveying," Crosby Lockwood & Co.; William Rickard, "The Miner's Manual," Longman & Co.

a rack and pinion, which is the means of diminishing or increasing the distance between the object-glass and the eye-piece.

That the horizontal axis may not be liable to bend with the weight of the telescope, it is made of two cones B B, whose bases are connected together to form the axis, and to the telescope by the sphere F, which form the nucleus of the instrument to which the tubes A A′, forming the telescope, and the two cones B B are attached. The apex of each cone is finished with a steel or bell-metal pivot turned and ground upon the axis as true as possible. These pivots work in V-formed sockets or Y's as they are technically called, which surmount the upright arms C C of the iron stand.

H is a spirit level striding across the instrument. This is used to determine the horizontality of the instrument. One or two thin brass plates are supplied. These are notched at their tops to receive a pin fixed in the end of the tube of the level H, to prevent its falling. The iron stand is fastened to the stone after it is placed in its true position by means of the screws K K.

To set the axis of the telescope truly horizontal, adjust the level H upon the pivots of the axis, and by turning a milled-headed screw *a* near the top of one of the arms. Any error must be corrected by raising or depressing the screw *a* on the stand, and by turning the capstan screws *b* at one end of the level, which raises or depresses the spirit-bubble with respect to its points of support. These rules are sufficient for the mining engineer, but for astronomical purposes more refined adjustment is required. When the position of the instrument has been settled, the screws K K are inserted in their sockets through the holes in the stand. Thus a very close approximation can be secured.

To make the subject of mine-surveying as comprehensive as possible, the following directions should be strictly attended to:—

Dialling with the Magnetic Needle.—Assuming that the ordinary dial is employed, the operator in commencing a survey fixes the tripod firmly, and then, guided by the spirit levels, carefully adjusts the instrument, either by the ball and socket joint or the adjusting screws, until the bubbles are centred. The dial-plate is then turned around until the south end of the needle (always distinguished) settles at 0° or 360°. Should the needle be sluggish, a gentle tap to the plate will cause a quivering and facilitate its progress to its proper position. Having clamped the instrument securely to the tripod, an angle can now be taken in any required direction by moving the sights around with the large thumb-screw. Having taken the observation, the degree on the inner graduated circle opposite the arrow on the *vernier scale* is recorded, together with the minutes which may be indicated by the same scale. Some practitioners read off the angle recorded by the north end of the needle, the movable sights being previously fastened at zero. But inasmuch as the above method should be adôpted in dialling without the needle, and being equally as expeditious and more accurate in taking fractional parts of a degree, the advantage of uniformly observing it is apparent.

Let A, Fig. 187, represent a shaft, and B C D E a subterraneous excavation in a northerly direction from it, the bearings of which are required. Having made sure that there is no iron near him, the dialler fixes his instrument

at B, to command two drafts. The plate is put into the position before described, and a back observation taken to A, and the degree indicated by the arrow in the vernier (which in this case, being a northerly drift, will be on the north side) is the direction of A B. The dialler then reverses his position, and takes a fore observation to C; the degree is read off, and this gives the course of B C. The next position for the dial is at D, the object at C being allowed to remain until the angle D C is determined. The previous operation to ascertain the direction of D E is repeated, and the survey terminates.

Fig. 187.

Dialling without the Needle.—It is well known that the magnetic-needle is disturbed by the influence of iron, and is consequently rendered unreliable by its presence. Serious errors having been, from time to time, fallen into by the counter attraction this metal offers, a system has been devised by which the magnetic-needle can be dispensed with, after a datum line has been obtained. The dial is carefully fixed in the manner already described, and the movable sights directed towards the objects stationed at the commencement of the survey. This should be a "candle rest" with spirit levels, and adjusting screws, mounted on a tripod, of precisely the same size and description as that on which the dial stands. The angle which the index or vernier records with the circular plate is then observed, and the dial unclamped and removed to the position occupied by the candle rest, and it is transferred to the dial tripod. The movable sights are kept in the same position, and the dial-plate moved around on its axis, until the candle at the first station of the dial is bisected. The circular plate is then rigidly clamped by the screw, and the instrument is ready to take an angle independently of the needle.

Whatever departure the needle may show from the north point is due to attraction, for, provided proper care has been exercised in the operation, the dial-plate will correctly indicate the magnetic meridian, and virtually supersede the needle throughout the whole survey. Occasionally the whole dialling may be verified by the last draft being out of the influence of iron, for if the south point of the needle corresponds with that on the circular plate its correctness is demonstrated.

In conducting a survey without the use of the needle, the instrument must be fixed at each respective station, and fore and back sights be taken alternately. The operation will be rendered clearer by the following example.

The direction and distances of the subterranean drift, containing iron rails and pipes, are required. To obtain a datum line the dial is fixed in a recess, or a section of the rails and pipes must be removed. The instructions previously given having been strictly observed, the sights are directed to the candle rest at A, and the degree (say 40°) carefully noted, but not permanently entered. Reversing the position of the instrument and candle rest, the dial-plate is moved round, with the sights still at 40°, until it bisects the candle. This gives the datum line correctly. The plate is then securely fastened, and the sights directed to B, which the vernier shows to be 10° distance, by

measurement 30 feet. The dial is then carried forward to the next post of observation B, the tripod on which it stood being allowed to remain undisturbed, for fixing the candle socket on, and with the sights still retained at 10°, the whole instrument is moved bodily around, until the perpendicular hair cuts the candle at A. This back observation being taken to keep the line of the magnetic meridian only, the angle is not recorded. The candle rest and tripod are now advanced to C, and the rack work controlling the movable sights of the dial brought into operation for ascertaining the angle from B to C, which by reference to the vernier we find is 1°, distance 50 feet. The position of the instrument and candle rest is again changed, and the preliminaries being attended to, the course from C to D is determined; this is 15° 35′, distance 35 feet 6 inches. We proceed in the same way to the station D, and get the direction of D E, which is 20° 45′, distance 29 feet 9 inches. This is the termination of the excavation. An opportunity may now be afforded, and the dialler should invariably avail himself of it, for testing the correctness of the survey.

FAULTS—THEIR INFLUENCE, &C.

Method of determining the Influence of Faults on Lodes.—In the section which is devoted to the consideration of mineral lodes and their formation, the subject of dislocations has not been neglected. It has now become necessary to examine the circumstance under which these fractures occur, and the rules by which the miner should be guided in his endeavours to recover that portion of any lode which has suffered by these disturbances.

The provincialisms employed to express the phenomena exhibited, as the results of movements in the rocks in which mineral lodes are found, should be thoroughly known. The following vocabulary, which is given by Mr. W. J. Henwood, should therefore be clearly understood:—

1. The rocks, whatever may be their character, are denominated . . . *The Country.*
2. All metalliferous veins . . . . *Lodes.*
3. All veins, *not metalliferous*, and in directions subtending considerable angles to those which are productive . . . . *Cross Courses.*
4. Horizontal galleries, if excavated in metalliferous veins . . . . *Levels.*
5. Ditto, ditto, not in metal veins . . . . *Cross Cuts.*
6. Pits open to surface . . . . *Shafts.*
7. Pits not open to surface, but extending on the dip of a vein from one gallery (*level*) to another . . . . *Winzes.*
8. All excavations horizontally . . . . *Driving.*
9. Ditto downwards . . . . *Sinking.*
10. Ditto upwards . . . . *Rising.*
11. Small veins, whether metalliferous or otherwise (in St. Just) . . . *Scorrans.*

The following terms are derived from other sources, and are used in Derbyshire and the Northern counties:—

a. The beginning of a shaft, on the very surface . . . . *The Eye of.*
b. When a dislocation comes slanting in before the miner as he cuts or sinks . *Slip-joint.*
c. When a dislocation runs along in the vein . . . . *Rider-joint.*
d. When a vein is dislocated and moved . . . . *A Leap.*
e. If two veins or pipes cross one another "right," or obliquely . . . *A Pee, or a Tye.*

In the Miners' Glossary, given in the Appendix, a number of other provincial words and Mining terms will be found.

Every intersection must be, either a simple running of one vein through another, or, a movement of the rocks producing what the miners call a *heave,*

or, in ordinary language, a *displacement*. If the lode is discovered by driving to the right on the cross vein, it is called a *right-hand heave*, but if it is approached on the left it is a *left-hand heave*. It will be readily understood that if a lode runs east and west through any rock, and if that rock suffers any disturbance, by which one portion of the rock is raised or falls down, that the lode will suffer a *heave* or a *slide*.

Mr. Henwood has recorded 272 intersections observed by himself. Of these 57 were unaccompanied by *heaves*; 181, or more than 84 per cent., were found by driving on the side of the greater angle; and 34, or less than 16 per cent., were on the side of the smaller angle. He gives the following table:—

Of all the lodes, the proportion intersected but not *heaved* is .	27·7	per cent
Of the tin lodes	18·0	,,
Of lodes yielding both tin and copper	37·2	,,
Of copper lodes	17·7	,,
Of all the lodes the proportion heaved towards the right hand is *.	51·1	,,
Of the tin lodes	56·0	,,
Of the lodes yielding both copper and tin	44·0	,,
Of the copper lodes	52·4	,,
Of all the *lodes* the proportion heaved towards the *left* hand is .	26·2	,,
Of tin lodes	26·0	,,
Of lodes yielding both tin and copper	18·6	,,
Of copper lodes	29·8	,,
Of all the lodes the proportion heaved towards the *greater angle* is	63·5	,,
Of the tin *lodes*	52·0	,,
Of *lodes* yielding both tin and copper	56·0	,,
Of copper lodes	74·2	,,
Of all the lodes the proportion *heaved* towards the smaller angle is	12·9	,,
Of the tin lodes	30·0	,,
Of lodes yielding both tin and copper	6·8	,,
Of copper lodes	8·8	,,
The mean distance of the heaves of all the lodes is . . .	16·4	feet.
,, ,, tin lodes	15·4	,,
,, ,, lodes yielding both tin and copper ore	14·6	,,
,, ,, copper lodes	17·5	,,
The mean distance of the *right-hand* heaves is	18 7	,,
,, ,, *left-hand*	12·0	,,
,, ,, heaves towards the greater angle . .	16·3	,,
,, ,, ,, ,, smaller angle . .	17·1	,,

This table is given for the purpose of showing the observed results of the dislocations. It has long been a habit amongst miners to speak of *heaves*, as if the lode had been an active agent in producing the phenomena. It must not, however, be forgotten that the *lode heaved* has no influence upon the *heave* itself. A mineral vein is formed in a fissure, which has been produced by some movement of the Earth's crust, the crack running, it may be, east and west. By the operation of another disturbance running at nearly right angles to, or at some angle with, the first disturbance, the *lode* is broken, and consequently, that portion of the lode between the fractured ends is moved or heaved.

Having endeavoured to give what appears to be the most simple explanations of the phenomena, which are often seriously perplexing to the miner—so much so that *heaves* are in many districts commonly known as *troubles*—it is only justice to Mr. Henwood, who has recorded more observations of these phenomena than any other man, to quote his views, which are given in a

* "It is remarkable that all the principal *heaves* in the district from Chacewater to Camborne should be to the *right*, while those to the *left* are but insignificant in comparison with them."—*Mr. Thomas's Report*.

section of his work, named by him "Relations between the Rocks and the Intersections of the Veins which traverse them":—

"From the difficulty of the inquiry, and its uncertainty, I cannot state whether the difference between these numbers (those given in the table, p. 669) depends merely on the much greater area occupied by the Slate than by the Granite in the tracts here considered, or whether the intersections of veins are really more common in one rock than in the other, under conditions otherwise similar.

"If we regard the total number in each rock as 100, then the respective proportions will be as follows, viz.:—

	In Granite.	In Slate.
The intersections without *heaves*	26·2 per cent.	21·5 per cent.
Heaves towards the *right hand*	52·4 ,,	50·5 ,,
,, ,, *left hand*	21·4 ,,	26·0 ,,
,, ,, *greater angle*	65·6 ,,	64·0 ,,
,, ,, *smaller angle*	8·2 ,,	14·5 ,,
The mean distance of all the *heaves* is		16·4 feet.
,, ,, ,, ,, in *Granite*		17·1 ,,
,, ,, ,, ,, in *Slate**		16·3 ,,

"The relative proportions seem scarcely sufficient to warrant the idea that the slight differences between them have much connection with the containing rock.

"It has been seen that the 233 intersections are effected by 125 veins of clay, or *flucans*; and 108 quartzose ones, or *cross courses*. The proportions on which they occur in the different rocks are—

	In Granite.	In Slate.
Flucan	78·7 per cent.	47·0 per cent.
Cross Courses	21·3 ,,	53·0 ,,

"This result is in accordance with the general fact long recognised in some parts of Cornwall, that the *cross veins* far more frequently partake of the nature of the contiguous rock (and are thus characterised as *flucans*) in the Granitic than in the Slaty rocks, and that in the latter they are much more generally quartzose in their composition, and are thus designated *cross courses*.

"The intersections of *cross veins* by lodes are 23 in number; of these 36 per cent. are in Granite and 64 per cent. in Slate.

"Twenty instances of *lodes* intersected by other lodes have been recorded, of which 20 per cent. are in Granite and 80 per cent. in Slate."

After giving several tables which appear to confirm his views, Mr. Henwood proceeds:—

"This inquiry has established the fact that the extent of the *heaves* is in direct proportion to the width of the lodes, as well as to that of the *cross veins*, whilst here it would, at first sight, appear that this part of our inquiry shows the extent of the *heaves* to be in direct proportion to the width of the cross veins, and in an inverse one to that of the lodes. It must not be forgotten, that a preceding investigation has *conclusively* proved, that the extent of the heaves are in direct proportion to the width of the *lodes*, as well as of the *cross veins*, and this would lead us to expect that the diminution of *energy* in the one class of veins would be compensated by the increase of it in the other; and therefore that as their opposing influences so exactly

* The average distance of the two heaves in the elvan at *Ting-Tang* is 14·5 feet.

counteract the other, any apparent difference in the result at different levels should be owing to the influence of depth alone."

Several isolated statements must now be selected from Mr. Henwood's copious observations:—

"The general rule undoubtedly is, that the *heave* of the *same lode*, by the same *cross vein*, is in the same direction (towards the same hand) at all depths; but, in a few instances, *lodes heaved* towards the *right hand* at one level are *heaved* towards the left at another." Mr. Carne states that at Gunnis Lake, at the depth of 70 fathoms, the lode is heaved 15 feet to *the left*, and at 10 fathoms deeper, it is heaved 15 feet to the right. (Is not this a movement of one section of the rock, while the other remains at rest?)

"In order, however, that a *heave* should take place, it does not seem absolutely necessary that the *lode* should be traversed either by *another lode*, a *cross vein*, or even by a joint of the rock; for at Balnoon the lodes are frequently cut off, and *heaved* by the joints of the rock, and often, too, when these are wanting (?). Of the latter kind there is also an instance at Dowgas, where four *lodes* abruptly terminate alike without the intervention of either joins or vein, and are again found to commence with similar abruptness, nearly at right angles, and at a distance of about 4 fathoms."

"The intersections of lodes by *flucans* show a numerical preponderance of *heaves* towards the greater angle, and also that the extent of the *heaves* is greater with tin than with copper veins, which also holds true in the *leaps* occurring with vertical intersections; whilst the displacement (whether a heave caused by a *flucan* or a leap occasioned by a *stick*) of copper lodes is more frequently towards the greater angle than is the case with *lodes* yielding other ores."

"Again, the *heaves of lodes* by each other and by *cross courses* exhibit a larger proportion of heaves towards the smaller angle than results from their heaves by flucans. The law most remarkably prevails in their vertical intersections also; for the *leaps* towards the smaller angle are in much larger proportion than those towards the greater angle; an excess which also holds good when the *leaps* caused by the intersections of *lodes* by each other are compared with those of *lodes* traversed by *slides*. The displacement, whether it be a *heave* or a *leap*, is far more commonly to the smaller angle when the traversing vein has a quartzose than when it has a clayey character. These circumstances rather indicate that the direction of the *heave* or *leap* may be affected by the mineral composition of the intersect, as we have already seen it is by the intersecting vein."

Especial attention should be directed to these quotations, which assume that the vein has a power which cannot be ascribed to it.

Professor Hanns Hoefer, of the Mining School of Leoben, has recently given the following methods for determining faults in mineral veins.*

The rule of Zimmermann has been usually followed. This assumes that the hanging wall of a *faulting-fissure* has slid downwards in the direction of its *dip*. But dislocations show many cases in which one part of the seam

* "Zeitschrift für Berg—und Hüttenwenen," vol. xxix. A careful abstract of this paper, by Dr. R. W. Raymond, was printed in the "Engineering and Mining Journal" of New York, of which he is one of the editors.

has been shoved over the other. The hanging-wall of the faulting-fissure has slid upwards instead of downward.

Every dislocation of mineral deposit by a cross fissure was long regarded as belonging to one or the other of these two classes; it was either a *slide* or a *heave*.

It is assumed that throughout a given fault the motion of the hanging-wall has been everywhere the same, and consequently that the so-called *throw*, determined by exploration of the two dislocated parts of the deposit, is a guide for exploration at all other points.

For the following illustrations we are indebted to a carefully-prepared abstract of Hoefer's memoir by Dr. R. W. Raymond, of New York.*

"This phenomenon itself suffices to show that the classification of dislocations is not so simple as has been supposed, and the methods pursued by mine surveyors, based upon that classification, may, therefore, need improvement. These methods, as is well known, assume that throughout a given fault the motion of the hanging-wall has been everywhere the same, and consequently that the so-called vertical interval or throw determined by exploration of the two dislocated parts of the deposits at any one point is a guide for exploration at all other points. Practice, however, shows that this guide is not unerring. It does not always agree with the indications of actual movement and direction furnished by the striations of the walls of the faulting-fissure. These marks frequently do not follow the dip, but obliquely across it. The oblique or other motion thus indicated is certainly one of the elements in the geometrical problem presented to the surveyor.

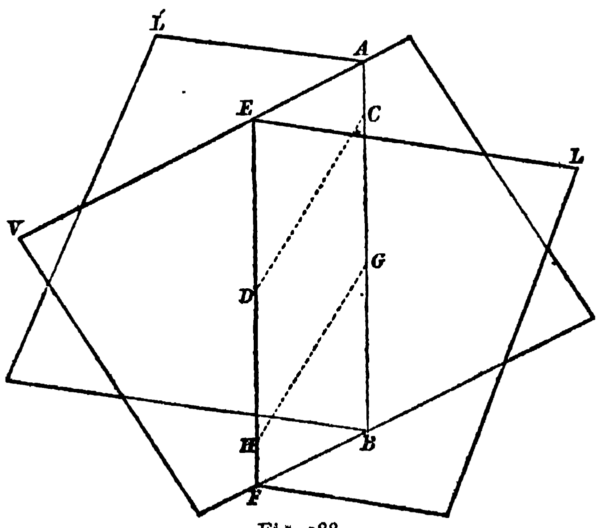

Fig. 188.

"Fig. 188 may illustrate this point. Let A B be the line of intersection between the vein L and the faulting-fissure V, the striations of which indicate that the movement took place in the direction of C D. The dislocated continuation L' of the vein being found at E F, the old rule would declare that the case was one of a heave, or upward movement, of the hanging-wall; and yet it is really an oblique slide. That the distinction is important appears when we consider that, if the vein being worked in the foot-wall of the faulting-fissure had contained an ore-body which was cut off by the fault at G, the old rule would require us to accept the continuation of this ore-body at some higher point in the hanging-wall of the fault; whereas, by the present hypothesis, it is at the lower point H to which the striations tend. It is

* "Transactions of the American Institute of Mining Engineers, 1882," being a paper read at the Washington meeting of that Society.

apparent that an oblique slide would not, according to the old rule, appear to be a slide at all, unless the striations (that is, the indication of actual movements) were steeper in dip than the lines of intersection. In case L' had been horizontally moved, the dislocation would, by the old rule, be *a slide* if it had moved in one direction, and *a heave* if it had moved in the other; whereas in reality it would have been neither."

But Professor Hoefer goes farther, and declares that the parallel uniform movement of the hanging-wall of a fault is not to be always assumed. The evidence of this statement is drawn especially from coal seams; not because the dislocations of these deposits are different in nature from those of metalliferous veins, but because coal-mining has furnished more extensive excavations, and therefore a greater body of evidence than any other branch of the business. Moreover, we can with greater certainty judge what was the original position of a coal-bed, than we can of a fissure-vein. When the latter suddenly changes dip, for instance, beyond a fault, we cannot be sure that the change of dip did not exist before the dislocation took place. This phenomenon of a change of dip and also of strike is frequent in coal-fields, under such conditions as make it reasonably certain that neither the original position of the coal nor irregularities in the faulting-fissure were the cause; but rather that the relative movement of the two parts of the deposit was not in parallel lines.

In many cases where veins show a uniform dip, that is, approach in form a regular plane, and yet exhibit these changes beyond a fault, it is reasonable to infer, instead of a simple *slide* or *heave*, a partial *revolution of the mass on the hanging-wall side of the fault* around an axis normal to the plane of the faulting-fissure. Professor Hoefer refers to a very extensive fault in the neighbourhood of Aix, which shows to the south-east a greater vertical dislocation than toward the north-west, which he thinks can only be explained by a *turning movement.* The centres of movement would be found at the intersection of perpendiculars drawn through the line of striations produced by the revolution.

"Thus, if striations were exposed, the intersection of the perpendiculars would show the centre of movement. In practice, however, it is likely that the several perpendiculars drawn through such striations would not intersect at a given point; and this would show that, besides the turning movement, there had also been a movement of translation of the whole mass, up, down, or along the plane of the fault. The complication of these two movements is, however, not beyond analysis, if the data are sufficiently abundant and exact. Even with the imperfect data usually afforded by the limited exposures in mines, it is much better to work upon a perfect than upon a crude and partial system; and Professor Hoefer thinks that not only the points already mentioned, but also the question of direction of movement, can in many cases be satisfactorily determined by the plan he proposes.

"This plan may be illustrated for a general case by Fig. 189. Let A B represent the course of a vein dipping 32° (as shown by the arrow), which has been explored on an upper level to where it is cut off by a cross-fissure having the strike B K and the dip of 40° (as shown by the arrow). Let it be assumed that upon a lower level the vein had been opened, with the strike

C D and the dip of 23°; that on this level a fault was encountered at D, having the same strike and dip as that at B. By a simple construction, with the help of the triangle *a b c*, in which the angle *c* is 40°, and the side *a b* is the vertical distance *h* between the two levels, we find the point *c* and draw the line *c* D, which, being parallel to B K, and also coinciding with the strike of the fault at D, proves the latter to be identical with the fault at B on the level above. We now determine the two lines of intersection E F and B G made by the fault, with the two portions A B and C D of the faulted vein. This can be done most easily by the aid of the two triangles, *d e f*, *g h i*, in which the base *h* is taken equal to the vertical distance between the two levels, and the angle opposite *h* is, in each case, the angle of the dip. A B and C D being already given, the corresponding lines, namely, H J on the level of C D, and K L on the level of A B, are to be found. This is done by drawing H J parallel to A B through the point *f*, and prolonging *h g* parallel to C D. The course of the fault at B is known; hence the line B K drawn on that course intersecting the line K L at K determines the point K for that level, while for the next lower level the point H is determined by producing the line C D parallel with B K;

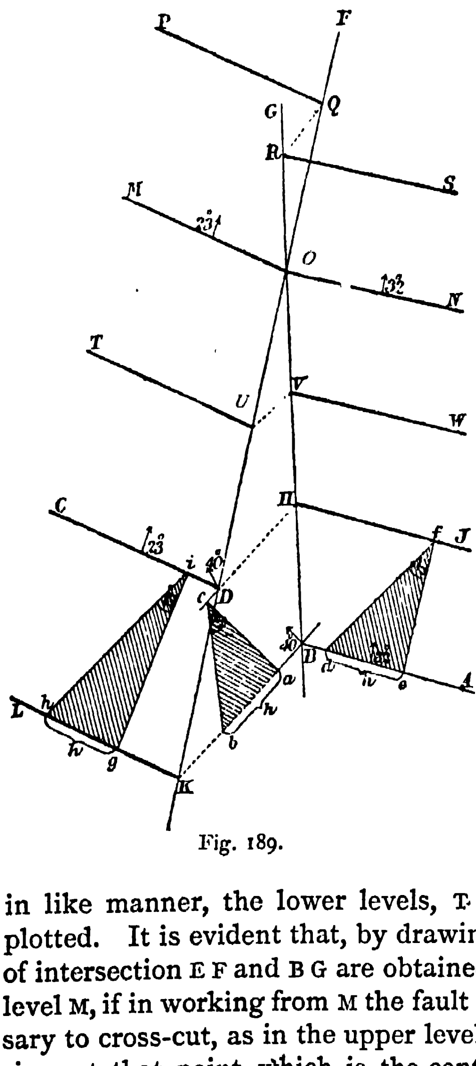

Fig. 189.

in like manner, the lower levels, T U, V W, M O N, P Q, R S, &c., can be plotted. It is evident that, by drawing lines through K D and B H, the lines of intersection E F and B G are obtained. It is evident also that on the fourth level M, if in working from M the fault is encountered at O, it will not be necessary to cross-cut, as in the upper levels, to find the continuation of the vein; since at that point, which is the centre of revolution, the vein can be found by simply breaking through the cross-fissure. In the next lower level, P Q, however, if the fault is encountered at Q, it will be necessary to cross-cut for the continuation of the vein in the direction Q R, a direction opposite to that which would be necessary at U or D."

It will be seen that in this case a revolution has been demonstrated without the help of the indications afforded by the striations.

Professor Hoefer indicates also how this graphic method may be applied to lines of intersection, which are not straight, but curved; and to the still more complicated case of a varying strike at different levels in the faulting-fissure itself; that is, for instance, when B K, H D, V U, and Q R are not parallel.

He recommends in practice the adoption of the method above described, on the ground that it involves no generic assumption or hypothesis, but makes the work of the surveyor in the first place purely descriptive, and also checks by graphic construction the errors of observations due to irregularities in the vein and fault. He points out also that this method indicates conclusions as to the nature of the movement which has taken place; since, if the two lines of intersection are parallel, the movement must have been parallel; while if they converge, the movement must have involved a revolution, and the points where they intersect must be the intersection of the axis of revolution with the plane of the fault.

Dr. Rossiter W. Raymond, in bringing a notice of Professor Hoefer's graphic method before the American Institute of Mining Engineers, observes that it will not indicate, in a case of compound movement involving both a revolution and a slide (Fig. 189), either the existence, the direction, or the amount of the displacement. Therefore, he argues that cases must often arise in which the method would fail in the direction of guiding the miner in search of the lode which has been lost through the influence of the faulty fissure.

In continuation of his argument, Professor Hoefer says:—

"The solution of the problem remains in principle the same when the lines of intersection are curves. If, for instance, we had plotted a fault for different levels (not too far apart vertically), and had found the facts on actual exploration to differ from our construction, that is, the lines of intersection, imagined as drawn in the plane of the fault, had proved in practice to be longer or shorter than required by our construction, we should then obtain a number of elements of the actual curved lines of intersection, which we could prolong according to their curvature, in order to operate further with them, just as if they were straight.

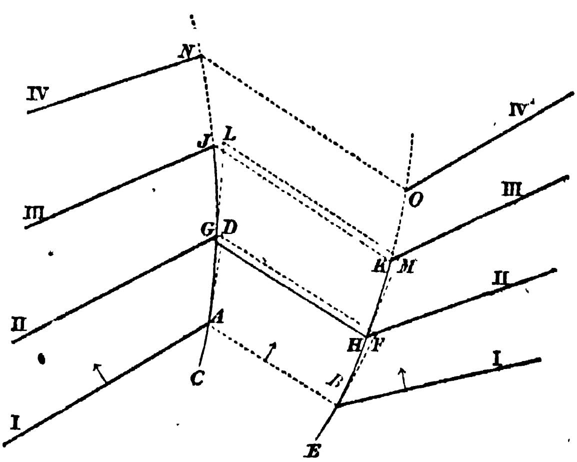

Fig. 190.

"To take an example: suppose (Fig. 190) that the fault had been encountered on level I, in the two portions of the vein, at A and B, giving at these points the straight lines of intersection A D and B F; but that on level I I the fault was found at G, not D, and the continuation at H, not F. Straight lines drawn from A through G, and from B through H, thus become the lines of intersection for the construction of the fault on level I I. But actual developments show the points sought to be J, K, instead of L, M; and, in short, we become able to prolong the curves A G J, B H K, as curves, and thus to obtain for lower levels, in advance of exploration, more accurate determinations."

Dr. R. W. Raymond's remarks on this method of plotting and deter-

mining faults in mineral deposits are of considerable value; his experience and strictly scientific training rendering him one of the most accurate observers of the phenomena of mineral veins to be found in the United States of America, and thoroughly qualified to discuss with Professor Hanns Hoefer of Leoben the geometrical method proposed by him. Dr. Raymond gives his opinion that the classification of dislocations is not so simple as has been supposed, and that the methods pursued by mine surveyors need improvement. This bears very strongly on the condition of many of the mine surveyors in this country, and their attention is therefore especially directed to the following remarks made by him at the Virginia meeting of the American Institute of Mining Engineers:—

"The relative position of the two parts of the faulted vein, shown in Fig. 190, may have been reached by a simple revolution around an axis normal to the fault at O, or by a revolution around some other axis normal to the fault, coupled with a slide along the fault. For instance, the axis of the revolution may have been at U, and the slide may have carried it *apparently* to O.

"Yet this is precisely the case which may be expected to be most frequently encountered in practice. Simple revolutions must be rare, if, indeed, they ever occur. My own impression on this point is confirmed by the reply of Professor Hoefer to an inquiry which I addressed to him after perusing his paper. He says:—

"'Circular movements, combined with movements in straight lines, are very frequent in our faults; in fact, I do not doubt at all, that a continued careful study will show them to be the rule. Whether simple revolutions often occur is very difficult to decide, from the observations thus far available. You know how one-sided and incomplete the inquiry has heretofore been in this direction. In the southernmost district of Przibram, the Clementi vein shows in its selvage striations, the varying directions of which indicate a circular movement; and my studies (unfortunately interrupted by my departure) led me in this case to the belief that the movement had been circular only. But I did not consider the question definitely settled.'

"In this case, the study of the striations in the faulting-fissure may give valuable, though perhaps rarely exact, indications as to the direction of movement. If the rectilinear movement followed the circular one, the striations may furnish a clear record of it in straight lines. If the two were (as is more probable) simultaneous, the striations would be strictly epicycloid curves; but for their interpretation it would be sufficiently accurate to consider them as fragments of ellipses, having their major axes inclined in the direction of the rectilinear movement. These indications would doubtless be, in most instances of practice, merely general guides to exploration. But after, by such exploration, the continuation of a given ore-body (as D, Fig. 189) had been found, it is plain that the whole movement of the faulted vein could be analyzed and plotted, and that the continuation of any other ore-body could be sought with confidence. In the case before us, it would be only requisite to determine the relations of the point actually found to D^1, its theoretical position on the hypothesis of purely circular motion; and

the correction thus applied to D^1 could be applied to any other point similarly determined.

"I should remark, in conclusion, that all these constructions rest upon the assumption that the dip of each segment of the faulted vein is constant. That is, the vein is treated as a plane. But it would not be difficult to include, in the method here shown, changes of dip and strike, as these might be discovered in actual working; and under certain circumstances, a change of dip might serve as a useful landmark in surveying. For instance, if, in Fig. 189, there were a change of dip in the left-hand portion of the vein, at the level C D, then the corresponding change of dip must be shown on the line G B, at the point formerly adjacent to D; and the discovery of this point would at once, as has been already shown, permit the analysis of the movement which had taken place, and the deduction of all its resultant relations."

Schmidt, a Bergmeister at Siegen, about 50 miles north-east of Cologne, was the first to recognise the exact effect of one lode crossing and dislocating the other, and he found *that the younger lode always carries the older lode downwards with it, according to the dip of the dislocating lode.* He therefore proposed the following rule of throw:—

First. Vertical Dislocation.—If the dislocating lode *dips towards you*, you must follow it *upwards* in order to find the continuation of the older lode; if the dislocating lode *falls from you*, you must follow it *downwards* to get at the older lode.

Second. Horizontal Dislocation.—You must follow the dislocation on the side of the *obtuse angle* which it forms with the thrown lode.

In some districts faults are observed to have occurred so, that several portions of the country have been dropped down in one direction, prolonging the surface appearance of some rocks beyond that which would otherwise have happened after the various denudations to which they might have been exposed. The amount of accumulation thus preserved, or the reverse, by systems of faults, is a subject which should engage the attention of miners and geologists as one of importance. As might be expected, lines of faults frequently exhibit minor complications, and even disturbances, showing a certain amount of *lateral pressure*, during the adjustment of their sides after the action of the force producing the original fracture.

De la Beche's "Observer"* will be found to contain many valuable observations on the occasion of faults. Whether faults arise from minor adjustments of the Earth's crust, the bending, contortion, and squeezing of various accumulations being regarded as more considerable consequences of these adjustments, or from other causes, together with the greater plications and flexures, they show a broken and dislocated condition of that crust which it requires the miner and geologist to bear in mind when endeavouring to trace the facts he may observe in connection with ore deposits and the movement of veins to their sources.

Attention is directed to Fig. 37, p. 204, showing a very elaborate set of faults occurring in the bottom of Penhalls mine, in St. Agnes. Here there are a succession of movements, up and down, all of them well marked by

* Consult "The Geological Observer," by Sir Henry T. de la Beche, C.B., F.R.S., 1853.

their influence on the lodes and "gossans" of that district. Captain Bennetts, the chief agent of Penhalls mine, has been enabled to determine that several considerable thicknesses of strata have been removed by denudation from the surface of the country.

A vertical section may only give the apparent movement of the parts of rocks fractured and faulted. It is, therefore, desirable that the miners should search for the direction of the friction marks, the line attending the pressure of the rocks on one side, against those on the other, in order to discover that in which the movement has really been effected. This investigation will sometimes lead him (Sir H. de la Beche remarks) to find that, though the general plane of a fault may dip in a given direction, the movement has not always corresponded with it. This is a most important matter for the miner to make out. Some of these friction marks bear evidence of the action of enormous pressure, more especially in those cases where the dislocations may, in its plane, be very considerable, and yet the rocks thus moved against each other, and once so far asunder, may be now closely joined together. The contents of dislocations, that is, of the fissure produced by the fracture, whether known as common faults or mineral veins, often present beautiful impressions of those friction marks;—parts of the walls of the fracture often grinding against each other in their movements, having finally left cavities in which various mineral substances were accumulated, taking the form of the surfaces against which their first deposit was effected.

COMMERCIAL NOTES.

Valuation of "Tin Stuff" (Tin Ore).—It has been customary to buy and sell tin ore by measure—the measure being arbitrary. Tin for a long period has been measured by the sack. This is due to the old practice of carrying the sacks of tin, from the mines to the smelting-house, on the backs of mules.

In some districts the *sack* contains 8 gallons; in others the sack varies 9 to 12, and even 18 gallons, of 282 cubic inches, or beer measure. There are some difficulties in ascertaining the value of the tin ore by measure. "The sample" taken for assay is by wine measure, the produce is weighed by troy weight, and the total quantity of tin is estimated by avoirdupois weight. Dr. Rickard, in his "Miners' Manual," says: "The following rule was very much employed some years since, and it will be seen that the buyer preserved a large margin for loss in dressing, as well as for profit. "Every pennyweight of black tin produced from a sample of one gill wine measure, will give 160 lbs. avoirdupois in 100 sacks of 18 gallons each beer measure; but the following example will show that for every pennyweight so obtained 240·932 lbs. avoirdupois would be nearer the truth. *Example*: Find the quantity of black tin in 100 sacks of 18 gallons of tin-stuff, when a gill produces 1 dwt. In one gallon there are 32 gills, this gives 32 dwts. per gallon; then $32 \times 18 = 576$ dwts. in every sack of 18 gallons wine measure. But 1 gallon beer measure will contain 1·22 gallon wine measure; therefore, $576 \times 1{\cdot}22 = 702{\cdot}76$ dwts. in one sack beer measure. And multiplying this by 100 we obtain 70.272 dwts. as the quantity of black tin in 100 sacks. But

24 grs. make 1 dwt., and 7,000 grs. make 1 lb. avoirdupois, as the real quantity of black tin contained in 100 sacks. Thus—

$$\frac{70272 \times 24}{7000} = \frac{1686528}{7000} = 240\cdot932 \text{ as above.}$$

The difference between 240·932 lbs. and 160 lbs. on every 100 sacks being 80·932 lbs., or rather more than one-third of the whole, was thus lost to the seller.

This is an example of the loose way in which the tin-miner's business has been transacted. The late Captain Charles Thomas, of Dolcoath, remarks, in his "Tin Tables": "This does not give the correct quantity of tin contained in 100 sacks, it only *pretends* to give such quantity as purchasers are inclined to purchase at, after allowing for profit," &c.

The only correct mode is to weigh the tin-stuff, as copper ores are weighed, deducting for loss by water, and taking any sufficient quantity of the ores by weight as the sample; weigh the produce by equal parts of the same weight. These equal parts may be twentieths, giving the produce at so much for twenty, as is the present practice among tin-smelters. At Dolcoath the assayer employs the usual copper assay weights, taking for the sample double the weight marked 100, and weighing the produce by the one-hundredth part; this of course gives double the produce.*

Sampling and Sale of Copper Ores.—In copper mines several "pairs" or companies of miners are generally employed in raising the ores. The produce of their labours, being nearly of the same quality, are generally mixed together in one heap called "*the parcel*," a sample being first taken from each company's pile, to ascertain the exact produce of it.

From the ores thus mixed, a sample is taken by the agents of the copper companies, and the whole "parcel" is sold according to the result of that sample. Copper ores are sold in Cornwall, and at Swansea, by public sale, which is known as the "*Copper Ticketings*." All ores are sampled by the companies' agents, or "samplers," a fortnight before the *ticketing* at which they are sold; thus three weeks' notice are usually given of that intention, by naming the day of sampling.

Copper is sold by the ton of 21 cwts. dry weight, the allowance for water being made according to the loss obtained by evaporating 1 lb. avoirdupois of the ore to dryness.

At each ticketing the chair is taken by the manager or purser of the mine which sells the largest quantity of ore.

The sale is by ticket. The agent of each copper-smelter present writes the prices per ton which he offers for each parcel in one mine on a slip of paper (a ticket), which is carefully folded and passed to the chairman. When all the tickets are collected the chairman opens them, and reads the offers of each company aloud, in the order in which they stand arranged in the ticketing paper, each offer being repeated by the vice-chairman. At these meetings blank forms are provided, on which each offer is entered under the name of the company making it. If two or more companies make the same offer the parcel is equally divided between them.

* Consult the "Miners' Manual of Arithmetic and Surveying," &c, &c., by William Rickard, in which will be found several problems carefully worked out.

Copper Ore Standard.—This term, the "standard," is called by Mr. Keates, the copper-smelter, "the everlasting stumbling-block of copper trade technicality." This gentleman communicated to Dr. Percy the following information on this subject*:—

"Originally there were few copper-smelters and few miners, and it was customary for the former to contract with the latter to buy their ores for periods varying from a quarter to one year, agreeing to pay them for the same according to a *standard* price of copper determined on, and which price was usually the selling price of *tough-cake* copper at the time. Thus, if copper were selling at £120 per ton, the *standard* was fixed at that rate or thereabouts. Out of this *standard* price the miner returned to the smelter a certain sum on every ton of ore sold (the ton of copper ore is always 2,352 lbs. or 21 cwts.), which for many years was 55s. per ton, though originally it was more. This was called the *returning charge.* The miner also gave the smelter 1 cwt. upon every ton to cover waste on removing the ore from the mine to the smelting works. The smelter was also allowed a varying number of pounds of ore in each ton as compensation for moisture in the ore, the bulk being weighed *wet*, while the assayer's sample was weighed *dry.*"

"*Example.*—Suppose a bargain made, and the ore weighed by the miner to consist of two parcels, one of 1,004 cwts., which is guessed to contain ½ cwt. of moisture per ton; the other of 800 cwts., which is guessed to contain ¾ cwt. of moisture per ton, so that in the first case the quantity of ore *paid for* is only 40 tons 14 cwts. 1 qr., and in the second case it is only 36 tons 15 cwts. 2 qrs. Let the first parcel produce by assay 10½ per cent., and the second 5½ per cent. of copper. In the first parcel the gross value of the copper in the ton of ore will be £12 12s., the *standard price* of copper being £120. For 100 parts of copper (say 1 ton) £120 :: 10½ parts : £12 12s. But from this gross value of the copper in the ton of ore the *returning charge* must be deducted. Thus, the gross value of the copper £12 12s., returning charge £2 15s., price per ton of ore £9 17s. In like manner the price of the second parcel of ore will be found to be £3 11s. Thus far the term *standard* is simple and intelligible, meaning neither more nor less than the *price of copper.*"

The smelter has no longer got his standard price of copper arranged with the miner as of old, but he opens his eyes to all the circumstances, or ought to do so. He sees what sort of ore he wants; he knows the rate of carriage and freight which he will have to incur on each parcel; he knows that one lot melts easily, another with difficulty, a third makes good copper, a fourth bad, and so on; and in the end he finds he has bought the five lots of ore above mentioned at the prices affixed. Immediately these *prices* are disclosed in the sale-room, the miners' and smelters' clerks proceed to calculate *the standard* in the following manner:—

	£	s.	d.
Prices of the ore of 5 per cent. produce	4	12	0
Add returning charge	2	15	0
	7	7	0

* "Metallurgy," vol. i. p. 304. By John Percy, M.D., F.R.S.

But this sum refers to the *ton of ore*, or 5 per cent. of the *ton of copper*, so that the standard of the ton of copper will be £7 7s. × 20 = £147.

Again:—

	£	s.	d.
Prices of the ore of 20 per cent. produce	21	15	0
Add returning charge	2	15	0

This multiplied by five gives the standard of £122 10s. Hence *the standard is now deduced from the price, and not the price from the standard, as formerly.* The buyer makes his offer without thinking of the standard. When the sale is over, the *average produce* of all the parcels of ore is determined, and also the *average standard*. Taking the five lots enumerated, the average produce is $12\frac{3}{16}$ nearly, and the average standard £132 4s. nearly. The only purpose which this modern standard serves is a ready mode of comparison of prices or of rates at which *copper in the ore* has been sold. For instance, instead of saying last week ores of 5 per cent. produce sold for such a sum, and this week they sold for such a sum, the phrase is, the standard is down a couple of pounds, or up £5, as the case may be.

The sources of the smelter's profit were—the care with which he got his ores transported from the mine to his works, so as to save as much as possible of the 1 cwt. of ore in each ton, which he did not pay for; the portion of the £2 15s. returning charge which was not actually expended in smelting; and the surplus or quantity of copper which his furnaces yielded in excess over the crucible of the assayer, and this of course would vary with the skill, as well of the assayer as of the smelter. Originally copper ores were dressed to a pretty uniform rate of produce, perhaps from 9 to 12 per cent. But the smelter, more acute than his neighbours, saw that he had better buy those of 5 per cent. and leave the others, because it took a less portion of the £2 15s. to smelt a ton of ore of 5 per cent. than in tons of ore of 15 per cent. produce. Now the simple mode of meeting this was to have had a varying scale of returning charges, instead of which these charges remained the same, while the standard was varied with the varying produce of the ores, so that with copper at £120 there might be a standard of £115 or £130, and thus the word "standard" lost its former simple and correct meaning. Competition went on increasing, processes were improved, carriage, freights, coals, &c., were lowered, but the *returning charge* continued the same, with of course less applicability than ever to the varying produce of the ores.

An illustration of what actually occurs at a modern sale will make the matter plain. Out of a modern sale of 3,000 or 4,000 tons of ore, varying in produce from 4 to 20 per cent., let us select the following lots with the prices at which they were sold:—

	£	s.	d.
100 tons of 5 per cent. produce	4	12	0
" 8 " "	8	1	0
" 12 " "	12	18	0
" 16 " "	17	8	0
" 20 " "	21	15	0

M. Moissenet, of the École des Mines, Paris, being in a difficulty, which will be readily understood, requested the author, as his friend, to ask some questions of Dr. Rickard, the author of "The Miners' Manual." The

following letters were the result. These so fully explain the difficulties that it will be right to print them in this place from the original MSS.:—

"I have taken the returning charges on copper ore at £2 15s. per ton in calculating for the price, which is quite correct; but in giving the rule for obtaing *one standard* from another I did not confine myself to any fixed returning charges, but gave it generally. In the examples, however, I have used the number £135, because the results agreed with those given in tables already published by Messrs. Jehu Hichens, Davey and others, which were considered near the truth. I have not, however, confined myself to that number, as you will perceive. In a communication to the *Mining Journal* last summer, I expressed an opinion that the average standard of the weekly sales is of no use to the miner, and that its only use is to compare the state of the market, in which case the £275 should be invariably employed. I will now go a step further, and state that in those mines where the average standard is made the basis of the division of money among the men, it is very frequently improperly divided, some getting too much and others too little for their ore.

"I am not a smelter, and consequently not an authority, but I think the following comparisons will prove that at least I have reason on my side.

"In order to find the standard at the ticketing, £2 15s. for every ton of ore are added to the amount of sale, and the result divided by the quantity of fine copper, irrespective of quantity sold; also the price of a ton of ore is found by multipyling the standard by the produce, and dividing by 100, deducting £2 15s. from the quotient; consequently the standard may be found from the price when the produce also is known. Applying this, then, to the sale of October 7th, 1858, of which I happen to have a few produces, I find the following, viz.:—

"Standard of sale, £123 19s. Produce, $7\frac{1}{8}$. Produces of three parcels of West Seton ores, three parcels of Clifford, and three parcels of South Wheal Francis, with prices, &c.

		Tons.		Price. £	s.	d.	Produce.	Calculated Standard.* £	s.	d.	Calculated Ore. Copper. £	s.	d.
West Seton mines	1.	78	at	2	7	0	$3\frac{3}{8}$	151	2	2	69	12	7
	2.	56	"	12	18	0	$13\frac{3}{4}$	113	16	4	93	16	4
	3.	43	"	5	9	6	$6\frac{1}{2}$	126	10	9	84	4	7
Clifford Amalgamated	1.	120	"	5	0	6	6	129	11	8	83	15	0
	2.	49	"	4	1	0	5	136	0	0	81	0	0
	3.	20	"	15	0	6	$16\frac{1}{4}$	109	7	8	92	9	2
South Wheal Francis	1.	77	"	6	1	0	$7\frac{1}{8}$	123	19	0	85	7	0
	2.	57	"	5	9	6	$6\frac{1}{2}$	126	10	9	84	4	7
	3.	55	"	10	12	6	$11\frac{3}{4}$	113	16	7	90	8	6

"You will perceive from the above that the price for ore copper varies for every produce, and that it follows no fixed rule—produce $11\frac{3}{4}$ bringing £90 8s. 6d.; $13\frac{3}{4}$, £93 16s. 4d.; while $16\frac{1}{4}$ brings only £92 9s. 2d.

"According to Davey's tables, the standard for $13\frac{3}{4}$ will be £114 16s. 5d., while by adopting £175, as in the *Mining Journal* reports, it would be only £112 2s. 5d.; but taking £275 the standard will be found £105 7s. 1d., the difference between which and the true standard as above, £113 16s. 4d., is £8 9s. 3d., and this is the difference between the prices given for the ore copper, and therefore the standard at par would be £105 7s. 1d. The

* Calculated from the produce and price.

standard obtained by using £175 is near the true standard; it does not, however, give either the true standard or the standard at par, nor is the difference constant. The following table shows the error:—

oduce.	True Standard. £	s.	d.	Standard calculated from £175. £	s.	d.	Difference of Standard. £	s.	d.	Difference of Price. s.	d.	
$3\frac{3}{8}$	151	2	2	151	4	4	0	2	2	—		
$13\frac{1}{4}$	113	16	4	112	2	5	1	13	11	4	10	too low.
$6\frac{1}{2}$	126	10	9	126	6	4	0	4	5	0	4	"
6	129	11	8	128	11	2	1	0	6	1	3	"
5	136	0	0	134	7	10	1	12	2	1	6	"
$16\frac{1}{4}$	109	7	8	110	3	8	0	16	0	2	5	too high.
$11\frac{1}{4}$	113	16	7	114	5	8	0	8	1	1	0	"

"Davey's tables give still greater variation. Hence I conclude that in comparing two standards according to the present mode of calculating the standard, the number £275 or £2 15s. per ton should be used; but that for the purposes of the miner the standard should in all cases be calculated from the produce and price, unless the smelter purchase at a price per unit of produce; at all events the miner should in every instance know the produce of his ore.

"Since I wrote on Thursday last I have looked carefully into M. Moissenet's questions, and find that by the rules given in the 'Miners' Manual' two at least of the three may be answered. The amount of returning charges employed in my examples, namely £135 per 100 tons, will not, however, give the exact rise or fall quoted in the journal; but on applying my rule to £175 per 100 tons, or £1 15s. per ton of ore, I obtain correct results; that is, my results agree with those in the *Mining Journal*, 'errors excepted.' And I find this a necessary condition; for instance, in the *Journal* for December 10, I find the rise in the standard on the corresponding sale for the previous month quoted at £3 1s. 6d., but it ought to be £3 7s. 6d. I will endeavour to answer M. Moissenet's questions.

"*Question* 1.—To find the rise or fall in the standard. The rule for this will be found at page 29 of the manual.

"*Example.*—The average standard of the sale, December 8, 1859, was £139 6s., the average produce being $6\frac{1}{2}$. On the 12th January the average standard was £145 10s., and produce $6\frac{3}{4}$. Required the rise or fall on the standard.

"Taking the returning charges at £175 per 100 tons of ore, the calculations will be as follows:—

	£	s.	d.
Standard for 8th Dec.	139	6	0
Subtract quotient of $\frac{175}{6\frac{1}{2}}$	26	18	5
	112	7	7
Add quotient of $\frac{175}{6\frac{3}{4}}$	25	18	6
Standard at par	138	6	0
Average standard Jan. 12th	145	10	0
Rise on standard	7	4	0

"Again, the average price on the 8th December is quoted at £6 6s. 6d., while on the 12th January it is £7 3s. It will be seen that the standard at

par for 6¾ is £138 6s. Calculating the price, then, for produce 6¾ at this standard, we obtain as follows:—

£	s.	d.		£	s.	d.	
138	6	0					
		6¾					
829	16	0					
69	3	0					
34	11	6					
9,43	10	6					
20							
6,70				9	6	8	
12				2	15	0	
8,46				6	11	8	price per ton at par.

"Then £7 3s., less £6 11s. 8d., will leave 11s. 4d. rise; but the rise quoted in the journal is 9s. 9d., which may be thus explained: the average produce is quoted at 6¾, being nearly ⅛th less than the truth; this at standard £145 10s. will give price £7 1s. 3d., only from which subtracting £6 11s. 8d., the difference 9s. 9d. agrees exactly with that given in the journal. The amount of sale divided by the number of tons of ore gives £7 3s. as the more correct average price of the sale.

"*Question* 2.—Given the standard £144 10s., and produce 6½, to find what standard should be given for the same kind of ore producing 4⅝.

"The rule for this will be found on page 28 of the manual, and taking the returning charges at £175 as before, we have—

	£	s.	d.
Given standard	144	10	0
Subtract $\frac{175}{6\frac{1}{2}}$	26	18	5
	117	11	7
Add $\frac{175}{8\frac{1}{2}}$	37	16	9
Standard at par for produce 4⅝	155	8	4

"Should the standard be required for 8½, then—

	£	s.	d.
To the above difference	117	11	7
Add $\frac{175}{8\frac{1}{2}}$	20	11	9
Standard at par for produce 8½	138	3	4

"*Question* 3.—I believe this question can only be answered generally. In the first place, the price for the ore copper is regulated by the richness of the ore, the quality of the metal it contains, and the wants of the smelters, ores from the same mine and containing metal of the same quality sometimes obtaining a different price for the ore copper. The miner, you are aware, has nothing to do but to submit. I believe the practice in Cornish mines is to advance 'subsist' to the tributers after their ores have been sampled and weighed and the produces obtained. An approximation is then made of the value of their ore from the standard of the most recent sale, and a certain proportion of the approximated earnings thus obtained is then paid the men in advance. Both agents and men can generally estimate the value of their ore sufficiently near for this purpose.

"I am not aware of there being any rules or tables in existence for making up the amounts in advance, as the final settlement or pay-day does not take

place until after the ores are sold and a sufficient time for making up the accounts.

"The only tables I am acquainted with at all relating to this portion of the mine accountant's duty are Davey's, Easall's, Provis', & Whitburn's tables for copper, and Captain Charles Thomas & Tregonning's for tin."

Standards at Par.—Two standards may be said to be proportionate or *at par*, when the same price per ton for fine copper of equal quality is the base in each; thus, if the copper in each of two parcels be of equal quality, but the returning charges on one parcel be different from those on the other, each may have a different standard, yet both be at "par," or on an equality with respect to the market.

Again, if two parcels contain copper differing in quality, each may have a different standard, and yet be at "par," or may have the same standard and not both be *at par*.

When the *standard* and produce of one parcel of ore are given, and also the produce of another, to find its *standard*—

Divide the *returning charges* of the first parcel by the produce, and subtract the quotient from the given standard; reserve this difference; then divide the returning charges of the second parcel by its produce and add this quotient to the reserved difference; the sum will be the *standard* required.

To find the rise or fall in the *standard* at the ticketing.

From the given standard and produce of one week's sale, and the given produce of another week's sale, find the standard at par for such sale by the former rule; then, if this standard agrees with that of the last sale, the market is at *par*; if not, the difference will show the rise or fall.

Estimation of Lead Ores.—The deductions usually made are for waste of ore, for loss in smelting, for the charges on freight and carriage, and for coals, and the other expenses incurred by the smelter, to which must be added the profits claimed by the smelter.

Nearly all ores of lead contain silver. The value of that silver should be added to the value of the lead in the ore. No addition, however, is made for any silver in the ore unless it exceeds 5 ozs. per ton of lead.

The *returning charges* are from £2 to £3 per ton; this includes carriage, freight, coals, and the smelter's profit.

In the lead mines of Cornwall and Wales the *tributers* raise the ores at a given price per ton, and the adventurers generally dress it, for which the men pay from 20s. to 40s. per ton, according to the quality of the stuff. The ore is brought to a certain produce agreed on, or a deduction is made for the deficiency. 21 cwts. dry weight is always considered as the ton.

In Cumberland the miners estimate the value of their ores by the *bing* of 8 cwts., reckoning so many bings per "shift," according to the quality of the ore, or *bouse*, as the ore from the mine is called.*

A "shift," is the quantity contained in six or eight waggons, and amount to about 240 kibbles of 14 quarts each. Each waggon in a six-waggon "shift" contains 40 such kibbles; while in an eight-waggon "shift" each waggon contains only 30 kibbles. The ore is dressed at a fixed price per *bing*, according to quality.

* "*Bouse* is that part of the vein that, in cutting the small or lesser sort of ore, cannot be separated from it."—*Miners' Dictionary*, by William Hooson, a Derbyshire miner.

CHARGES FOR DRESSING LEAD ORE.

			s.	d.	
Bouse, or ore stuff, containing ½ a bing per shift			9	6	per bing.
,,	,,	1 bing ,,	6	3	,,
,,	,,	1½ ,, ,,	5	0	,,
,,	,,	2 ,, ,,	4	4	,,
,,	,,	2½ ,, ,,	3	11	,,
,,	,,	3 ,, ,,	3	7	,,
,,	,,	3½ ,, ,,	3	5	,,
,,	,,	4 ,, ,,	3	3	,,

These prices range from 12s. to £1 3s. 9d. per ton.

Valuing the Ore in the Vein.—The miner estimates that a vein of solid lead ore 1 inch wide will produce 1 bing 3 cwts. 2 qrs. 24 lbs. 8 ozs., or about 1 bing 3¾ cwts. of lead ore per square fathom; this is equal to 11 cwts. 2 qrs. 24 lbs. 8 ozs.

Value of Ground.—It is important that the agent of a miner should be enabled to find the weight of any ore per square fathom in a vein of given thickness. The weight of the ore may be approximated to form its specific gravity and the average size of the vein when this is solid; frequently, however, other substances are associated with the ores in the vein, or the vein itself is not solid, and therefore the judgment of the agent is put to a severe test. Sometimes the ores of copper are sold with mixture of silicious matter; the specific gravity is then the best guide.

The ores of tin and lead are nearly always freed from the waste, then the specific gravity of the waste may be omitted.

The following table, constructed by Dr. Rickard, gives the solid feet of the most usual metals forming the matrices of the veins in which they occur. To find the weight of ore per square fathom in a vein, multiply the number opposite the ore by the number of cubic feet in a square fathom of the vein at a given thickness. If a portion of the matrix be taken with the ore, the average weight of one foot should be taken.

A vein 6 feet square and 1 inch thick will measure 3 cubic feet; therefore to find the cubic feet multiply the thickness in inches by 3.

Metals and Ores.	Weight.	Metals and Ores.	Weight.
GOLD. Native	1230	ANTIMONY. Sulphide	281·25
,, —	750	,, Oxide	345·12
SILVER. Native	643·75	MANGANESE	212·5
,, Vitreous	449·37	,, Binoxide	300·0
,, Red	362·5	,, Wad	231·25
,, Horn	287·5	,, Psilomelan	250·
COPPER. Native	525	NICKEL. Arsenical	450·25
,, Vitreous	543·75	,, Sulphide	281·25
,, Pyrites	259·37	,, Glance	381·25
,, Purple	312·5	COBALT. Ton white	400·
,, Gray	296 87	IRON. Native	456·25
,, Red	375·	,, Pyrites	500·
,, Malachite	250·	,, Magnetic ores	512·5
TIN. Oxide	406·75	,, Arsenical	581·25
,, Sulphide	268·75	,, Hæmatite brown	225·0
LEAD. Native	709·37	URANIUM. Pitch blende	404·73
,, Sulphide, Galena	468·75	BARYTA. Heavy spar	268·75
,, Carbonate	403·75	,, Carbonate	do. nearly.
ZINC. Blende	250·	LIME. Calc-spar	156·25
,, Red oxide	337·5	FLUOR. Spar	196·25
,, Carbonate	268·75	SILICA. Quartz	162·5
ANTIMONY. Native	412·5		

CHAPTER IV.

DRESSING OF METALLIFEROUS ORES—PREPARATION FOR THE SMELTER.

THE dressing of ores consists in effecting a mechanical separation of earthy matter or gangue from metalliferous products. The conditions to be observed are to effect the operations cheaply and to obtain the largest amount of ore possible. To this end certain metalliferous ores may be sufficiently massive, and pure in themselves, to be ready for the smelting furnace, after the mere operation has been performed of picking out the pieces of *gangue* with which they may be associated. Generally, however, the "vein-stuff" sent to the dressing-floors includes (1) solid or "prill" ore, (2) mixed or "dredge" ore, (3) fine ore or "smalls." Copper, Lead, Zinc, and Pyritic ores are usually composed of these several varieties of *stuff*, but in "tinstone" the particles of oxide of tin are usually so small, and so thoroughly diffused with gangue, as to place it within the category of *dredge stuff*, although this term is never substituted for tinstone by the tin-miner. To separate metalliferous substances from vein-stuff by the combined action of machinery and water recourse must be had to the crushing or stamping mill as well as to the sizing trommel, classifier, jigger, and buddle. Before referring to inventions comprising modern dressing machinery, it is desirable to observe that dressing or separating ore from veinstone can only be effected by adhering to the principle of *sizing grains of different densities* into grains of *equal volume*, or otherwise classifying grains of *equal velocities of fall* into grains of *different dimensions*. Somehow or other this result must be accomplished, either by a direct or indirect method, before light grains can be separated from heavy ones, or grains of equal fall in water can be isolated from large and small ones. Forty years ago or more the inclined screen and hand riddle comprised the principal sizing apparatus for large-grained stuff, but jigger, buddle work, and slimes were only indirectly sized and concentrated in the dressing appliances themselves. Even now in Cornwall, indirect classification is pursued in the dressing of tinstone; the "middle" or mixed tin product undergoing a rude kind of classification and a series of concentrations to afford "heads" or merchantable black tin. The distinctive method of dressing prevailing in Germany in the sixteenth century was doubtless introduced into this country by Germans. About the year 1562 Queen Elizabeth, acting on the advice of her Council, sent to Germany for some experienced miners to explore the mineral districts of England and Wales, and upon their arrival granted them a monopoly of all the mines in Wales and eight English counties. Later on, in 1565, all the mines and minerals

in the remainder of the kingdom, and in the "English pale" in Ireland, were granted to another German co-partnery, so that at this time the mining operations of the kingdom were—perhaps with the exception of the tin mines of Cornwall—under the direction of, if not actually worked by, German miners. In 1583 "Dutche" miners were employed in developing lead and copper mines in Cornwall. Not only is there ample evidence of the large employment of Germans in the mines and smelting works of this country in the sixteenth century, but the dressing apparatus known to be in use down to the end of the succeeding century were similar to those illustrated in Agricola's work "De re Metallica," published at Basle in 1546. This writer, whose real name was Bauer, and who resided in the Saxon Erzgeberge, in his eighth book of the work referred to, describes and illustrates the picking-table, &c. Descriptions and illustrations of the ore-dressing processes followed, and of the apparatus employed in this country, which were but few in number until within recent years.

Carew gives a clear account of tin-dressing as practised in the year 1602. At that time "ragging, bucking, and cobbing hammers were used to prepare the tin-stuff for the stamps, in which apparatus it was eventually reduced; the black tin was then concentrated on 'green turves,' and vanned or 'shogged' in a bowl to 'flit away' any earthy substance left." Carew's quaint description may be reproduced entire :—

"As much almost dooth it exceede credite, that the tynne, for and in so small quantitie digged vp with so great toyle, and passing afterwards thorow the managing of so many hands, ere it come to sale, should be any way able to acquite the cost; for being once brought aboue ground in the stone, it is first broken in peeces with hammers and then carryed, either in waynes or on horses backs, to a stamping-mill, where three, and in some places sixe great logges of timber, bounde at the ends with yron, and lifted vp and downe by a wheele driven with the water, doe break it smaller. The streame, after it hath forsaken the mill, is made to fall by certainne degrees, one somewhat distant from another, upon each of which, at every discent, lyeth a green turfe, three or four foot square, and one foot thicke. On this the tynner layeth a certayne portion of the sandie tynne, and with his shuell softly tosseth the same to and fro, that through thus stirring the water which runneth over it, may wash away the light earth from the tynne, which, of a heauier substance, lyeth fast on the turfe. Hauing so cleansed one portion, he setteth the same aside, and beginneth with another, vntill his labour take end with his taske. After it is thus washed, they put the remnant into a wooden dish, broad, flat, and round, being about two foote ouer, and having two handles fastened at the sides by which they softly shogge the same to and fro in the water between their legges, as they sit ouer it, untill whatsoever of the earthie substance that was left be flited away. Some of later time with a sleighter inuention and lighter labour, doe cause certayne boyes to stir it vp and down with their feete, which worketh the same effect; the residue after this often cleansing, they calle black tynne. But sithence I gathered sticks to the building of this poor nest, Sir Francis Godolphin entertained a Duch mynerall-man, and, taking light from his experience, but building thereon farre more profitable conclusions of his owne inuention,

hath practised a more saving way in these matters, and, besides, made tynne with good profit of that refuse which tynners rejected as nothing worth."

In 1758 Dr. Borlase, in his "Natural History of Cornwall," describes the dressing of tin and copper ore as then practised in the western part of that county.

After noticing that the richer sorts of ore were kept together underground in the copper mines, he remarks: "What comes from the people below," he says, "is re-examined as soon as it arrives at the mouth of the shaft; the best is broken small with hammers, which they call *spalling*, or brought away to the adjacent bucking-mills, where there are men ready to bruise it upon a rock with a short bar of iron, and thence carried to the heap of best ore, and what is not worthy of the first place is laid by to make another sortment; the best small ore (which consists of the smaller fragments of what has been broken and sorted before) is then washed and sifted into a tub or *keeve*, as near to the shaft as possible (to prevent waste), first through an iron sieve, or *searce*, called in Cornwall the "griddle," the *meases* about an inch square; here the waste or barren stone, by washing, is discovered and thrown away, while the copper in it, sorted into *best* and *dredged* (that is streaked; spotted, powdered ore which requires a second washing), and the larger pieces of ore of each sortment are thus divided: what passes through the griddle is taken up out of the keeve and put through another searce of smaller meash called the "*jigging searce*," which has eight holes in every square inch; here, when it has been lifted up and down, and turned round in the searce a few times (which they call jigging), the waste will all rise to the top and settle in the middle like small sand, and what remains underneath will be clean ore. The poorer sort, which is the streaked or dredged ore, is carried from the mine to the next adjoining stream of water, where, in several pits made for the purpose called the *strakes*, it is washed clean. All the richest bits of ore are then culled from the rest by girls or boys, at the hire of 4d. per day, and the poorest or most stony parts, which are not fit to be put with the picked ore, are carried to a stamping-mill, there pounded and passed through a rough grate. What ore remains in the forepart of the pit (into which the pounded ore was washed from the stamps) is carried back to the jigging searce and worked as before mentioned, but what runs off the hindmost part of the pit and remains there in the second pit (similar to that in the tin pits), is slimy, and must be trunked, buddled, and tozed as the slimy tin."

One hundred and seventy-six years after the date of Carew's publication, Pryce, in his work,* published in 1778, devotes two chapters to the dressing of ores: the first, Book IV., entitled, "The Method of Sampling and Vanning of Tin Stuff, with the Stamping, Burning or Calcining, and Dressing the same, with the manner of Dressing the Leavings, Loobs, &c.;" the second, being headed "Of Dressing Copper and Lead Ores, and Sampling Copper Ores for Sale." The illustration appended to the chapter on tin-dressing shows an overshot water-wheel, six heads of stamps, catch-pits, jigging buddle, trunk, rack frame, and kieve. Similar appliances are illustrated in Agricola's work, hence it

* "Mineralogia Cornubiensis."

may be inferred that Sir Francis Godolphin rather applied the experience of the "Dutche mynerall-man" than built "thereon farre more profitable conclusions of his own inuention."

In 1821 Westgarth Forster published "A Treatise on a Section of the Strata from Newcastle-upon-Tyne to the Mountain of Cross Fell in Cumberland," * and he has given a chapter "On the Washing and Dressing of Lead Ores." He observes: "Metals are seldom found in a pure state, gold, silver, and sometimes copper excepted. The others usually occur in the state of ores, that is united with sulphur or some other mineralising substance and blended with a variety of extraneous matter so as not to possess the ductility or other qualities of metals. When they are procured in this state the first operation is to separate the ore, of whatever kind it may be, from its bed or matrix." In the description of lead-dressing which follows he refers to the washing-kiln and grate, to the crushing-mill, stamping-mill, bucker, hand-sieve, brake-sieve, running, stirring, and nicking buddle, dolly-tub, slime-pits and hush-gullies, and he illustrates a tripple roller crushing-mill, stamping-mill, flat buddle, brake-sieve, trunk-buddle, stirring and nicking buddles, and dolly-tub. In reference to jigging this writer makes the following pertinent observations: "The washers put what they call *a bedding* upon the bottom of the sieve in order to prevent the *smiddum* (rough ore) from passing too quickly through. It must be observed that, owing to the superior specific gravity of the particles of ore contained in this mass, they pass through the *bedding* and *sieve* while the operation of braking or tilting is going on, and the particles of stone, spar, &c., remain above the *bedding*, which are scraped off with the *limp*." And then he is careful to explain "that the bedding consists of a quantity of the smallest of the sieve ore laid on the bottom of the sieve in the form of a layer about two inches thick, and when the sieve is working the shaking of it by the boy at the end of the lever or brake causes the particles of ore that are among the tails to pass through the bedding and openings of the sieve into the tub, the bedding not being that close to prevent the ore from passing through it. This bedding, and the mechanical opening of the grains by means of pistons or plungers reciprocating in water, form the essential features of "fine sand" continuous jiggers in use at this time, but instead of removing the "tails" or "waste" by means of a limp it is drifted away by a stream of water running over the sieves. Various improvements in the washing of lead ore seem to have been introduced in the first twenty years of this century. During that period the crushing-mill and brake-sieve were evidently introduced into the mines of Cumberland and Derbyshire.†

In April, 1831, John Taylor, F.R.S., Treasurer of the Geological Society, contributed to the "Quarterly Mining Review" a paper entitled, "Notice on some Improvements in dressing Ores," wherein he observes: "I have often thought that the operations for dressing ores have not received so much attention among British miners as they deserve, and the cause of this neglect it is perhaps not very difficult to trace.

* A new edition of this work has been recently published.

† In the second volume of the "Transactions of the Royal Geological Society of Cornwall," page 386, Borlase describes the preparation of tin in St. Just, especially with reference to the minerals of that

It will be found that the ores in Great Britain are generally rich, compared with those of many districts on the Continent, and our miners have not, therefore, been stimulated to attempt minute savings. Fuel for smelting is also cheap and abundant in this country, therefore a concentration of the metallic parts by fire is often better than that by mechanical methods, or what we properly call dressing.

Notwithstanding that such reasons have some force in them, they are not sufficient to warrant us in being inattentive to the subject, and it is especially desirable to excite a more general and active pursuit of inquiry and experiment.

In a valuable paper on the "Mining Districts of Cardiganshire and Montgomeryshire," by Mr. Warington W. Smyth, published in the second volume of the "Memoirs of the Geological Survey, 1848," a clear and comprehensive description is given of the dressing of lead ores at the Goginan mines. Mr. Smyth illustrated the round buddle, the tye, the strake, and the flat buddle. He also gave a plan of the Goginan dressing-floors.

In a small work published by Phillips and Darlington in 1857, entitled "Records of Mining and Metallurgy," twenty-three pages were devoted to "crushing and dressing machinery." The descriptive matter contains some important statistics bearing on crushing and grinding mills, moisture in ore, and cost of dressing ores, &c.

In 1857 M. Moissenet, then of the École des Mines, Paris, made an excursion into Cornwall, and produced a valuable paper on the mechanical preparation of tin. Not only did he visit several tin mines, but he investigated and described each distinct process, and gave complete statistics of the percentage weight of black tin contained in various products obtained in different parts of individual machines. He also set out in a scientific manner the order followed for effecting the enrichment of the black tin, and appended to his paper three sheets of illustrations, which included forty-three figures of the machinery and apparatus then in use. In 1866 M. Moissenet published an equally complete paper on the dressing of lead ore at the Lisburne mines, Cardiganshire, and illustrated it with thirty-two figures, showing the floors and their dressing appliances.

In 1858 Mr. James Henderson, C.E., read a paper at the Institution of Civil Engineers "On the Methods generally adopted in Cornwall in dressing Tin and Copper Ores." This paper is highly interesting for the number and completeness of the drawings which accompanied it; they are comprised in two sheets, the first entitled "Tin Ore Dressing Machinery," the second, "Copper Ore Dressing Machinery." The tin apparatus includes excellent illustrations of steam stamps, flat and round buddles, separators' hand and rack frames, tossing, packing, and vanning tubs, strips, tye, Brunton's calciner, burning-house furnace, and arsenic flues; while in the copper-dressing appliances are included the slides, ragging and spalling, a picking-table, hand and circular riddles, bucking-bench, cobbing, anvil, the brake-sieve, steam-jigs, and crushing-mill. In the paper itself he briefly described

district. A detailed account of tin-dressing in the central mining district of Cornwall by the late William Jory Henwood, is to be found in the "Transactions of the Geological Society of Cornwall," vol. iv. p. 145, A.D. 1828. According to this writer trunking machinery was introduced into Cornish mines about the year 1825.

these various operations. Julius von Sparre, Bergmeister of Eisleben, an accomplished mathematician, published in the Bergwerksfreund, in the year 1858, "Contributions to the Art of dressing Ore." He may be fairly said to have preceded Rittinger in many of his investigations, and to have framed several important axioms of great practical value to the ore-dresser.

In 1860 John Darlington contributed to Ure's "Dictionary of Arts, Manufactures, and Mines," a lengthy paper entitled "Dressing of Ores." In the edition published in 1875 the description with illustrations extended to eighty pages, and in the supplement published in 1878 eleven additional pages were given. In the "Mining and Smelting Magazine," a most valuable work in six volumes, 1862 to 1864, edited by the late Henry Curwen Salmon, many interesting papers are included on lead and tin-dressing machinery.

At a meeting of the members of the Institution of Civil Engineers, held on the 5th of April, 1870, Mr. Thos. Sopwith, jun., read a lengthy paper on "The Dressing of Lead Ores," in which he described the continuous jigger as then constructed at Kalk, Cologne, and referred to a definite method of sizing the crushed stuff by means of trommels.

Bergrath Gaetzschmann, of Freyberg, in his work "Die Aufbereitung," treats ore-dressing as an art. His work of 1,408 pages, with forty plates, and an illustration of almost every dressing-machine known at the time of the publication of the work (1864 to 1872), gives a complete history of the practice of ore-dressing and apparatus employed since the middle of the sixteenth century.

Rittinger's "Lehrbuch der Aufbereitungs Kunde," or Text Book of the Science of Ore-dressing, was published in 1867 to 1870. This work consists of 686 pages of text, and of an atlas containing forty-one plates, which includes illustrations of all the important dressing-machines then in use. Rittinger not only gave the fullest attention to the theoretical and scientific axioms governing the art of dressing ore, but he may be said to have completely formulated the scientific principles upon which successful ore-dressing must ever be conducted.

On the 30th July, 1873, Mr. Henry I. Ferguson, of Truro, read at the annual meeting of members of the Society of Mechanical Engineers, held at Penzance, a comprehensive paper "On the Mechanical Appliances used for dressing Tin and Copper Ores in Cornwall," which was accompanied by valuable illustrations. At the same meeting Mr. Charles D. Taylor, of Devoran—of the firm of John Taylor & Sons—described the tin stream works in Restronguet Creek, near Truro, and a continuous jigger, impeller buddle, and classifying box used in dressing oxide of tin. During the last six years many useful papers on tin stamping and dressing machinery have appeared in the "Proceedings of the Mining Institute of Cornwall," notably by Mr. R. H. Williams, of Cuddra, St. Austell, the late Mr. John Hocking, Messrs. R. A. Varden, M. Loam, W. Teague, jun., and W. Husband, of Hayle. The latter gentleman has also given a valuable paper on "Stamping Machinery."

Mr. J. M. Cazin, of New York, contributed a series of papers,* entitled "Dynamical Metallurgy, or Mechanical Ore Concentration." In his introductory remarks the following observations occur: "Dynamical

* "Mining Record," vols. x. and xi.

metallurgy attempts the qualitative increase in value by arranging (moving) the components of minerals so as to (physically) separate and collect the valuable minerals from those bearing no value, without attempting any change in the chemical (elementary) constitution either of the total (ore) or of the parts. The products are a local concentration of particles of value and a decrease in their intermixture with parts having little if any value.

"The methods of chemical metallurgy are called either wet or dry processes—*dry* when heat is applied, and *wet* when liquids are applied. Dry processes applied in chemical metallurgy are roasting, smelting, sublimation, distillation, evaporation, and crystallization. Wet processes applied in chemical metallurgy are amalgamation, extraction, precipitation, cementation, and solution. Both these dry and wet processes are called "reduction." The methods of dynamical metallurgy are likewise called either dry or wet processes—dry (pneumatic) when air is applied as the dynamical medium, and wet when water or any other liquid is applied as the dynamical medium for changing the local arrangement of particles constituting the mineral (ore).

"The name of dynamical metallurgy has been introduced by me because all other names formerly applied to this science and art are more or less deficient in their meaning. In practice, nevertheless, their use may well be preserved for what they mean, namely, mechanical ore concentration, ore separation, or ore dressing."

Cazin next proceeds to develop "theories of dynamical metallurgy," and assigns the merit of extending our knowledge of the existing relative action of liquids, and submerged solids, to Von Sparre, Von Dem-Borne, and to P. von Rittinger.

Among the chief mechanical inventions introduced during the present century are the crushing-mill, stone-breaker, sizing-trommel, classifier, continuous jigger, round buddle, and automatic dead frame. It is impossible to state the circumstances which led up, as it were, to the several inventions, but the names of one or two individuals who assiduously promoted the art of dressing and mining deserve to be recorded and held in honourable remembrance.

About the year 1796 Mr. John Taylor, the founder of the firm of Messrs. John Taylor and Sons, took charge of Wheal Friendship in Devonshire. Among other inventions applicable to mining he introduced the crushing-mill in 1806 at the Crowndale copper mines, near Tavistock. At that time the price of copper was high, and the Crowndale ore occurring much intermixed with veinstone, the amount of labour being then insufficient to dress the stuff, Mr. Taylor took two lengths of cast-iron pipe of 16 or 18 inches diameter, and made these serve as cylinders or rolls. As this primitive crusher gave satisfactory results, properly-constructed mills were subsequently made and employed in the eastern part of Cornwall near St. Austell, especially at Pembroke, Lanescot, Fowey Consols, and East Crennis mines.

The first crushing-mill in North Wales was erected at the Halkin mines in 1823 by Mr. John Taylor, and in 1831 his son, the late Mr. Richard Taylor,

introduced the crushing-mill into the Consolidated mines, Gwennap. From that time to the present, the roller crushing-mill has formed the principal apparatus for reducing mixed lead and copper ores for the jigger, buddle, and other concentrating apparatus. The tumbling-shafts and weight-levers to keep the rolls together, the riddle under the rolls for dividing the stuff into jigger and crusher work, and the raft-wheel for returning the latter product to the rolls, were applied by Cornish engineers.

The first jigging-machine erected in Cornwall was introduced by the late Mr. Richard Taylor at the Consolidated mines, Gwennap, in the year 1831. At these mines considerable dislike was manifested towards the mechanical jigger. It was anticipated that all the persons then engaged in jigging the ores would be thrown out of employment and starved, and it was a matter of some difficulty to convince the people of the inefficiency of the old method, and that a great deal of valuable stuff was lost through its use.

Two highly important improvements in mechanical jigging were made between the years 1828 and 1830. One by the late Thomas Petherick, manager of Lanescot and Fowey Consols mines, near St. Blazey; the other, probably under the auspices of Mr. Taylor the elder, in one of the Tavistock mines. Petherick's hydraulic jigger consisted of a movable plunger, fixed sieves, an automatic hopper, and receptacles beneath the sieves for collecting the ore. The waste was removed from the sieves by means of a limp, and in this respect it differed only from the automatic action of the modern continuous jigger.

In 1828 a revolution in the system of jigging is said to have been effected in Hungary by an engineer named Tutsenak, who appears to have successfully devised a mechanical jigger.

The triple roll crushing-mill was introduced in the North of England; while the disc springs, of india-rubber and iron, and the arrangement for maintaining a constant pressure on the rolls at any given distance from their respective faces, are details due to German engineers.

The stone-breaker was invented in America in 1858 by Mr. Blake, since which time this machine has found its way into the chief mining and metallurgical establishments of every country. Some modifications of parts have been made by various English, French, and German engineers, but they have all failed in devising a machine capable of superseding the main part of Blake's invention—the use of jaw-pieces for breaking large stones into stones of small dimensions.

Jigging was formerly done with a small common round sieve by boys, who had to work stooping, so that their heads were down near the surface of the water-tank in which the sieves were used, these tanks, too, being sunk in the ground. The operation was both laborious and tedious, and many hands were required to get through large quantities of stuff. In Derbyshire, and in the lead districts which derived their practice chiefly from that county, an improved jigging apparatus was used early in the present century. A sieve was hung upon the end of a lever, and motion at once given to a large portion of stuff held in the sieve. Improvements in mounting the sieve were introduced at Wheal Betsey—a lead mine near Tavistock—but were not applied to copper ores until a considerable period afterwards. The modifi-

cations in the arrangement of the lever-jigger were probably made between the years 1820 and 1830.

About the year 1830 Captain Barratt, of Grassington mines, in Yorkshire, had hung the lever-sieve so that it could be worked mechanically. The late Mr. John Taylor the elder, writing to the "Quarterly Mining Review" in April, 1831, after noticing Petherick's stationary sieves, states: "The other method has been that of giving motion to the sieves hanging in water, in the same way as the Derbyshire break-sieves do. This has been admirably accomplished by Captain Barratt, of Grassington, where several sieves are worked by one small water-wheel, and the effect is excellent, and the expense of the process is so much reduced, that very poor work is now returned with profit that would not have paid upon the old plan."

On the 23rd June, 1843, Nicholas Troughton patented what appears to have been the *first continuous jigger.* The arrangement consisted of a long hutch, a sieve suspended to a rocking shaft, a driving eccentric and a fly-wheel. The sieve was set in a deep frame, and divided into four triangular-shaped receptacles. It was also fitted with two flap valves. The stuff was passed to the first of the receptacles from a hopper set on the top of the hutch and over the sieve. By means of the valves referred to, and the "jig" movement imparted to the sieves, the stuff was not only "settled" and classified, but the water admitted through the valves during the downward movement of the piston swept the stuff forward, separating the waste from the ore and dredge work.

In 1864 Henry C. Salmon published, in the volume of the "Mining and Smelting Magazine," a description with illustrations of a "new continuous jigging-machine of the Harz," and remarked: "Until very recently both the rich and poor lead ores of the mines of the Upper Harz, of a size ranging from one-twelfth to one-twenty-fifth of an inch, had been dressed by means of the ordinary strake, tye, and buddle, a process which, however simple in itself, consumes an undue proportion of time and labour, and greatly depends besides for its effectiveness on the attention of the attendant. For the last two years this process has been superseded with the most satisfactory results for ores of the size mentioned by a continuous jigging-machine." The machine consisted of a piston and stationary sieve, the latter slightly inclined downward to a point at the centre, with vertical discharge-pipe from the centre of the sieve, and covered with an adjustable cylinder for regulating the rate of discharging the concentrated ore. The late Mr. John Hunt patented in this country, on the 8th of March, 1866, a continuous jigging-machine. Several machines were constructed by him, which consisted of two sieves divided by a bridge, two ore chambers, and a pipe for delivering water to the apparatus. In Hunt's specification some of the functions of the fine-sand jigger claimed by later patentees are described. At the present time continuous jiggers include a variety of forms, some good and others bad in principle; but Casin's observations on the value of a good continuous jigger are to the effect that with a properly-constructed and well-regulated jigger, with an automatic "feed" and "discharge" of the waste and concentrated ore, no praise of the machine can be overdone. A competent ore-dresser can make it work absolutely at will to meet the requirements of any special case.

The elements of action subject to modification are—(1) a given volume of water may be continuously supplied to the first sieve; (2) the volume of water may be increased to the second and third sieves; (3) water may be supplied under or over each sieve and piston; (4) the quality and quantity of bedding on each of the sieves may be modified at will; (5) the number of strokes per minute and length of stroke may be arranged to suit particular kinds of stuff; (6) the length of stroke of each piston may be set according to the necessities of the case.

The merit of inventing the plunger *continuous* jigger belongs, according to Gaetzschmann and other German writers, to Vogl of Joachimsthall and Wimmer of Clausthal, who brought out their plans almost simultaneously about the year 1850.

Sizing trommels for sorting ores for jiggers were employed at Great Devon Consols by Isaac Richards in the year 1856. The highest development of the trommel system is to be found in Germany, where the most accurate sizing of ore prevails, and where trommels of all kinds may be found. Many years ago Mr. Brunton invented a separator for the purpose of sizing stuff by letting it fall through a column of water in a cylinder about 10 feet high, which he placed over a rotating trough divided into a series of compartments or cells. As this trough rotated, the cells within it were brought successively under an orifice at the bottom of the cylinder, the largest grains, falling most rapidly through the column of the water, reached the bottom of the cylinder first, and found their way into a cell, and the trough, travelling forwards, the next size fell into a second cell, and so on. The trough was of an annular form, and made one revolution for each charge of tin stuff to the cylinder. A separator of this construction was set to work at Tincroft, but the results were not satisfactory.

Later, Bergmeister Hundt, of Seigen, endeavoured to give effect to the idea of dressing ore by an almost similar kind of apparatus, but he also appears not to have realised satisfactory results. In 1856 Richards employed a classifier at the Great Devon Consols; and Captain Ball, of the Cardiganshire mines, who had effected many improvements in the details of dressing machinery, introduced the classifier into the lead-dressing floors of a mine near Aberystwith. This classifier consisted of a rectangular-shaped box and a vertical launder for conveying water under pressure to the box itself. The more scientifically constructed *spitzkasten*, or triangular-shaped box, is of German origin. The separating cone, a series of which may be made to constitute a classifier, was introduced by Mr. Borlase of Redruth, at Allenheads, in Cumberland, about the year 1857. The round convex buddle was first used in Cardiganshire about the year 1848. Subsequently, Phillips and Darlington designed a concave buddle, and later, in 1856, Hundt of Seigen introduced a concave buddle into some of the neighbouring mines of that place. Borlase also modified the details both of the concave and convex buddles. An automatic dead frame, now a distinctive feature on the Cornish tin floors, was designed by Vincent and introduced at Cook's Kitchen about the year 1860.

Railroads were only generally used on the dressing-floors of mines of this country from the year 1818.

On the subject of the transport of ore and stuff from one point to another, Mr. John Taylor the elder, writing in 1831, makes the following remarks:—

"The transport in various directions of large masses of stuff used to be attended with considerable charges; these are now much reduced, not only by the means that the railroads themselves afford, but also in many cases from improvements in the arrangement of the different processes on the dressing-floors, which have been suggested by the use of the railroads, and which have made important alterations by avoiding that handling backwards and forwards which was too much the former practice, and which of itself occasioned considerable expense. One of the best instances of arrangements of this sort, connected by well-constructed railroads, is to be seen at the mines belonging to the Duke of Devonshire at Grassington, and which reflects much credit upon Captain Barratt, the resident agent, who has laid out the most systematic plan of ore-dressing that I know of."

Upon the subject of slime-dressing Mr. J. Taylor wrote (1831): "In the first place I may notice that, some years ago, all the slimes from the ores in the lead mines of the North of England were suffered to be carried off by the water, and nothing was extracted from them until a man called Tratham, from Cornwall, acquainted with tin-dressing, wandered thither and began to dress them, the art of doing which remained for a long time confined to him and his family, and one of his sons is still working in this way, on the floors originally constructed by his father, at Nenthead, on Alston Moor, where, indeed, is still the only stamping-mill that I have seen in that district. The value of the ores in the slimes is, however, now well understood there; and we see, in the Lead Company's Works in particular, a system of well-arranged slime-pits for catching them, and some well-conducted processes for dressing them."

With the foregoing preliminary observations it may be desirable to proceed to the consideration of the various hypotheses bearing generally on the mechanical preparation of ores for the smelter, to describe the more important varieties of dressing machinery, and to refer to the ores to which they are applied.

(1.) Metalliferous ores, obtained from lodes or veins, are generally associated with ROCK and mineral substances known as *gangue* or veinstone.

The ROCK, usually of a fragmentary character, is mostly similar to that enclosing the lode, while the mineral substances are generally constituents of the enclosing rock, or of rocks in fissure connection, with the lode itself.

Although a lode may be known as being productive of a particular ore, yet it may also contain two or three other distinct ores. Galena (sulphide of lead) is frequently associated with blende (sulphide of zinc), and occasionally with iron and copper pyrites. Copper ore also exists in close connection with oxide of tin, and oxide of tin with wolfram or tungstate of iron.

In many lodes an ore exists distinct in itself [galena or copper pyrites], in others, two or more ores are closely aggregated together [sulphide of silver and sulphide of lead], or, as in the case of "Bluestone" of the Isle

of Anglesea, which is a mineral composed of sulphide of lead, zinc, copper, silver, and a little gold.

Ores are either massive or mixed. In the first division the ore is of considerable size, and almost free and distinct from veinstone, an example being the great veins of pyrites at Rio Tinto, while mixed ore may be subdivided into ore associated with veinstone in such manner as to be readily detached from the latter by means of a cobbing hammer; or ore so intimately intermixed with the veinstone as to render crushing or stamping machinery necessary for the purpose of effecting its concentration.

Metallic ores are either comparatively hard or soft [Iron pyrites, H=6·0—6·5; Galena, H=2·0—2·5], these terms being used in their ordinary sense, or friable, as in the case of black oxide of copper. Ores may also occur in a granular form, as the lead ore of commerce (Rhenish Prussia) [grains of galena and quartz feebly cemented together], or as pisolitic iron ore from the iron mines near Belfast. In order to more readily compare or identify ores they have been grouped into ten divisions of hardness, ranging from talc, with a hardness of 1, to the diamond with a hardness of 10. When more exact means are not available an approximation of the hardness is given by the following tests: The hardness of the finger-nail is about 2·5, that of copper 3, and that of white iron 4·5. Window glass varies from 5·0 to 5·5, and a file from 6 to 7; while flint has a hardness of 7. Of the few minerals that exceed flint in hardness corundum or emery (hardness 9) is the only one that need be noticed here.

The relative hardness and brittleness of one ore with another, and with the associated veinstone, is a point of economic importance in their mechanical enrichment. Sulphide of silver, H 2·0—2·5, and lead ore, H 2·5, are often found in mechanical combination with each other, and when such ore is reduced and concentrated in water, an appreciable portion of the more brittle and precious ore [$Aq.^2 S.$] frequently floats away and is lost.

Brittleness must not be mistaken for hardness. Many minerals, too hard to be scratched, are readily powdered by the edge of the knife, while other minerals of a minute crystalline or foliaceous structure yield, when broken, a considerable quantity of scale-like dust [*dust of fracture.*]

In order to smelt ores successfully and economically in the furnace, it is in most cases necessary to free the same previous to their reduction from adhering or mixed veinstone; this process, a mechanical one, is technically known as "*ore-dressing.*"

Specific Gravity of Metals, Minerals, and Earthy Substances.—By the specific gravity of a substance is understood its weight as compared with that of an equal bulk of some other body taken as a standard.* Water is always the standard of comparison for minerals; thus the specific gravity of water is 1, that of gold is 19·3, meaning that, bulk for bulk, gold is 19·3 times heavier than water.

The weight of a cubic foot of water is 62·425 lbs., and the specific gravity of galena is 7·5. If, therefore, it should be required to determine the weight of a cubic foot of this ore it will only be necessary to multiply 62·425 by 7·5, giving 468·18 lbs. The weight of any other ore or mineral substance may

* For Table of Specific Gravities, see Appendix.

in like manner be ascertained. The specific gravity of quartz is 2·6. If 2·6 be multiplied by 62·425, the weight of a cubic foot of this mineral is also obtained.

The mineral to be examined for its specific gravity should be free, as far as possible, from foreign substances, and it should not have many hollow or drusey cavities.

METHOD WITH HYDROSTATIC BALANCE (FIG. 191).

(*a*) Weigh the mineral carefully in an ordinary balance.
(*b*) Suspend the mineral by a horse-hair, and let the mineral dip well below the surface of the water in some convenient vessel and again weigh it, taking care to dislodge any air bubbles that may be seen on the specimen.
(*c*) Subtract the weight from that of, the difference will be the weight of a bulk of water exactly equal to the specimen.
(*d*) Divide the weight by the difference, the quotient will be the specific gravity.

Example. (*a*) Weight in air . 57·1 grs.
(*b*) „ „ water. 42·4 „

(*c*) Difference . . 14·7 „
(*d*) Then 57·1 divided by 1·47 gives 3·88 as the specific gravity of the mineral.

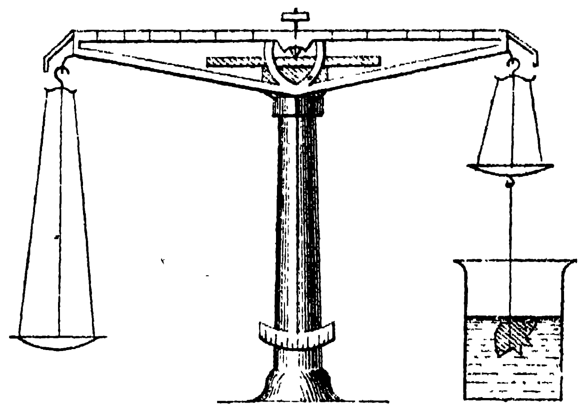

Fig. 191.

METHOD WITH SPECIFIC GRAVITY BOTTLE.

In cases where but small fragments of a substance can be obtained, an instrument, which can be readily procured from any good philosophical instrument maker, is most conveniently employed. This consists of a small bottle, of which the stopper is nicely fitted by grinding and is traversed by a capillary tube, the stopper being so arranged that it cannot sink beyond a line marked on the neck of the phial. By this means it is easy to obtain a constant weight of water in the instrument, since, if it be filled beyond the line and the stopper afterwards forced into it, the superfluous liquid will escape through the capillary tube and the bottle remain exactly full.

(*a*) Let the bottle hold a given weight of water, say 500 grains, fill the bottle with water, insert the stopper and wipe it dry, then make a counterpoise of exactly the weight of the filled bottle.
(*b*) Weigh off any convenient quantity of the specimen less than the capacity of the bottle, and in fragments sufficiently small to go in.
(*c*) Put the weighed fragments into the bottle, taking care to lose none. Now as the bottle was already *filled* with water, some will during this operation run out, whilst it is evident that the water thus removed must be of exactly the same bulk as the mineral introduced. Having again inserted the stopper, and weighed the bottle, it will be found that the counterpoise, together with a smaller number of weights than those used to balance the fragments in the scale pan, will produce equilibrium.
(*d*) The difference will be the weight of the displaced water or, of the bulk of water, equal to the specimen.
(*e*) Divide the weight of the mineral in (*b*) by the difference (*d*), the result will be the specific gravity required.

Example.—Three hundred and fifty grains of sand were carefully weighed and placed in the bottle, when, besides the counterpoise, 241 grains were required to produce equilibrium.

(*b*) Weight of sand in air . . . . 350 grains.
(*c*) " " water . . . . 241 "

(*d*) Difference . . . . 109 "
(*e*) Then 350 divided by 109 gives 3·21 specific gravity of the sand.

In order to determine approximately if grains of mineral and ore will separate from each other through the medium of water, it is sometimes advantageous to consult a table of specific gravities, for which see the Appendix.

By consulting the table of hardness and specific gravity of metallic ores and minerals the following points may be approximately determined:—

(*a*) Whether an ore can be separated from its gangue and veinstone both readily and cheaply, and if by means of simple dressing appliances.
(*b*) If a serious loss of ore is likely to occur in so separating it from its gangue or from the minerals with which it may be intermixed or associated.
(*c*) Grains of galena and quartz can be readily separated by water dressing, since the specific gravity of the former is 7·5 and the latter 2·6, a difference of 4·9. But if ore consisting of copper pyrites, blende, and carbonate of iron associated together be treated in a similar manner, the separation will be very imperfect and correspondingly unsatisfactory.

Copper Pyrites specific gravity	4·15	
Blende	4·02	Difference 0·13
Carbonate of Iron	4·1	" 0·05

These figures show that the specific weights of each of these ores in water differ but slightly from each other, hence if the grains of one ore should present a little more surface than the grains of another, which is practically unavoidable, or even if the grains should have an equal amount of surface and the mechanical treatment be but slightly imperfect, the attempt to separate such ores will be rendered unsuccessful.

(*a*) Grains of galena [spec. grav. 7·5] associated with carbonate of lime [spec. grav. 2·6] and Clay-Slate [spec. grav. 2·5] will not only separate readily from the two latter substances when falling in water, but from the great difference in density existing between grains of equal volume a considerable variation of their relative sizes may be allowed without risk of obtaining an unsatisfactory result. It therefore follows with such an admixture of ore and veinstone that but few mechanical appliances will be required for the concentration of the ore, and that the dressing process will be a short and cheap one.

(*b*) Although the loss of ore occurring in water-dressing will depend upon many circumstances, yet it is certain that if an ore be considerably softer than its gangue and much less in its relative proportion to the latter substance, the effect of crushing, pounding, or triturating the metalliferous stone will be to reduce the ore into grains of lesser dimensions than those constituting the detached matrix, to produce dust of fracture and slime, and perhaps to bring a portion of the ore into a form in which the effect of gravity, as manifested in the falling velocity of the grains, will be more than neutralised by the mere movement of a feeble current of water.

Estimation of Ore and Loss in Dressing.—Ore stuff, when delivered to the dressing-floors, will contain a given percentage and quantity of metal. In concentrating ore more or less mixed with veinstone and rock, no matter how carefully the process may be conducted, a metallic loss will always occur. In order to determine the extent and percentage of this loss it will

be convenient to reduce a ton of ordinary metal to units, *one hundred of such units representing a ton*, and, in the case of any given weight of metalliferous stuff, to ascertain the number of units of metal which it may contain.

In certain expressions employed in referring to this subject, percentages of metal and units of metal are intended to mean one and the same thing. Stuff assaying $3\frac{1}{2}$ per cent. gives also $3\frac{1}{2}$ units of metal; but if stuff should assay 7 per cent. or 7 units of metal, and the dressing loss should be $3\frac{1}{2}$ units, the loss in this case will *not* be $3\frac{1}{2}$ *per cent.*, but $3\frac{1}{2}$ units or 50 per cent. of the initial quantity of metal present.

The percentage assay of a ton of ore is also the number of units of metal contained in the ore; hence, if it be required to ascertain the number of units and tons of metal contained in a given pile of stuff, it will be sufficient to multiply the number of tons by the percentage—the result will be the total number of units of metal therein—and then to divide the product by 100, so as to obtain the tons and the decimal parts of a ton.

Example. Ore stuff 3211 tons—Assay 3 per cent.
Then $3211 \times 3 = 9633$ units of metal.
And $\frac{9633}{100} = 96{\cdot}33$ tons of metal.

The loss in dressing is the difference between the quantity of metal present in the initial ore and that which is found in the dressed product. If 3,211 tons of stuff afforded 96·33 units or 96·33 tons of metal, and after dressing only 115 tons of ore of 75 per cent., the loss will be 1,008 units, or equal to $10\frac{4}{10}$ per cent. of the initial quantity of metal.

Thus :—3211 tons of stuff at 3 per cent.	=	9633 units.
115 ,, ore at 75 ,,	=	8625 ,,
Loss		1008 ,,

Or $\frac{1008 \times 100}{9633} = 10\frac{4}{10}$ per cent. of the initial quantity of metal in the undressed stuff.

The loss of metal which occurs in water-dressing will more or less depend, as already to a certain extent indicated, upon certain physical and mechanical conditions of the stuff itself.

Physical.—Relative difference of densities in the ore and mineral to be treated.

Relative hardness of one of the constituent ores with one another and with the veinstone.

Relative degree of brittleness and proportion in which ore and veinstone may be associated together, as well as the degree of "toughness" with which the grains may adhere to each other previous to the reduction of the stone.

Mechanical.—Nature and extent of the mechanical treatment to which ores and veinstone may be subjected.

Examples of actual Losses of Metal—Copper Ore.—Blue and green carbonate of copper intermixed with hard quartz, clay, steatite, and jasperite. Assay of 222 tons of stuff before reduction in stamps $3\frac{3}{4}$ per cent., or $3\frac{3}{4}$ units of metal per ton of stuff. Total number of units of copper contained ($222 \times 3\frac{3}{4}$) 832, or $8\frac{3}{10}$ tons of metallic copper.

Mode of Treatment.—The stuff was crushed by Cornish stamps. Weight of head, 5 cwts.; height of fall, 8 inches; diameter of gratehole, 2 millimetres. Stuff passed through stamps' grates into strips, and twice buddled.

	Units.	Tons of Metal.		Units.		Tons of Metal
Ore obtained 6 tons, which afforded			Stuff treated, 222 tons at			
14 units of copper per ton or	84	0·84	$3\frac{3}{4}$ units of copper per ton	832	or	8·32
Loss in dressing 216 tons	748	7·48				
	832	8·32		832	or	8·32

Tailings.—The tailings, 216 tons, carried off 748 units of metal or $89\frac{9}{10}$ per cent. of the total quantity of copper present in 222 tons of stuff.

The ore was attached to the quartz in minute particles or films just in sufficient quantity to slightly increase the density of the latter. Comparatively fine stamping was therefore a necessity, and in so detaching the ore it was rendered more or less foliaceous, and formed scummy flecks on the water passing through the dressing apparatus.

Sulphide of Lead.—This ore, finely and closely intermixed with iron pyrites and oxide of iron, was subjected to various methods of enrichment. In each case the assay of the stuff before treatment afforded 17 per cent. of metal.

Quantity of Stuff by Weight.	Quantity by Weight of Ore.	Percentage Loss of the Metal originally present.
10 tons washed and concentrated to	$2\frac{1}{2}$ tons	61 per cent.
10 " " "	4 "	39
10 " burnt, roasted, and concentrated	2 "	57
24 " washed and concentrated	$4\frac{3}{10}$ "	$37\frac{1}{2}$
13·6 tons washed and concentrated	4 "	50
8 " roasted, washed, and concentrated	$4\frac{2}{10}$ "	33
8 " " "	$6\frac{9}{10}$ "	$16\frac{3}{4}$

Sulphide of lead, fine grain, partly dressed, assay, lead $42\frac{1}{2}$ per cent., silver $11\frac{1}{10}$ ounces per ton; $34\frac{3}{10}$ tons crushed and redressed obtained $14\frac{6}{10}$ tons, assay $54\frac{1}{2}$ per cent.; silver, 11 ounces per ton of ore. In this example the produce was raised 12 units per ton of ore, at a loss of 49 per cent. of the quantity of lead, and 95 ounces of silver, originally present in the partially-dressed ore. The money loss attending the experiment, after making the several charges and allowances incident to the metallurgic reduction, was £91 14s., or £2 14s. per ton on the original weight.

Silver Ore.—Silver ores *per se* rarely exist in sufficient quantities to render their treatment necessary by the common process of dressing. Such ores are, however, frequently found in close combination with sulphide of lead, antimony, or copper.

When sulphide of silver is present with sulphide of lead, the association is probably a mechanical one, since it is found that the more the grains of ore are broken and subjected to the action of a current of water, the greater is the loss of sulphide of silver. The following results were obtained from the enrichment of many thousand tons of fine grain sulphide of lead.

Cobbed or selected ore not dressed in water afforded	15·9	ozs. of silver	per ton of ore.
Sieve raggings reduced and jigged	"	15·1	"	"
Ore and veinstone, crushed and jigged	"	12·1	"	"
Slimes from crushing rolls and jiggers	"	10·4	"	"

The loss of silver in sieve raggings converted into slimes consequent on a finer state of mechanical subdivision and treatment in water amounted to ($15{\cdot}1 - 10{\cdot}4$) $4\frac{7}{10}$ ounces of silver per ton of ore. In this example the dressing was well conducted, every care having been taken to obtain the maximum quantity of cobbed ore, to size the stuff properly, and to limit its reduction to the average size of grains so as to afford the greatest amount of dressed ore.

Broadly stated, the loss of metal which will occur in the mechanical treatment of ore and the cost of enrichment will be *small*—

If the ore is fairly hard and breaks into smaller pieces without producing much dust of fracture.

If the ore is in itself of considerable density, and consists mostly of large grains easily detached from a gangue of much lighter specific weight.

If the enriching operation is chiefly confined to hand-picking, and if only a small proportion of the stuff sent to the floor is subjected to water treatment.

Whilst the *loss* of ore and cost of dressing will be considerable—

If the constituents of the ore and veinstone are composed of very small grains uniformly aggregated together.

If the ore and veinstone are nearly alike in density.

If the ore is so friable as to disintegrate into a powder by the absorption and mechanical action of water.

If the ore is sparingly associated or intermixed with veinstone, or if the veinstone is hard and the ore soft, or if both are subjected to severe pounding action.

If the ore in itself bears a high percentage of metal—as in the case of carbonate of copper, 57 per cent.—and simply stains the veinstone.

If a soft ore, thinly distributed or intermixed with hard veinstone, is pounded so as to shatter instead of detaching the orey particles.

The loss which occurs in enriching of ore usually commences with the crushing or reducing operation. In many cases ore is distributed or associated with the veinstone so irregularly as to render the assay of a sample drawn from a pile of vein stuff a very uncertain indication of its metallic contents. It is, however, always a simple operation to take a sample from the sand and slime tailings, and to determine with tolerable accuracy the amount of metal they contain Thus samples may be obtained in the castaways from the coarse and fine sand jiggers, the buddles, and the fine slime enriching tables.

A practical and useful method of ascertaining the approximate loss of ore in tailings is to construct four sample boxes for the tailings from coarse and fine sand jiggers, buddles, and slimes.

At the end of every month to sample and assay the contents of each box.

Some gangues, such as the white carbonate of lime and barytes, will distinctly show if an appreciable quantity of lead or copper ore is present; but the darker-coloured gangues or veinstones will not exhibit the ore so readily.

In a large and well-conducted undertaking the tailings should frequently be examined and periodically assayed. It will always be satisfactory to

know that the ore is obtained from the veinstone without incurring any considerable loss, and that the enriching process is economically and well conducted, while such results, carefully tabulated, will probably serve as an incentive to still further progress and improvement.

High Percentage Ore Dressing.—The interest of the smelter and miner is not relatively the same. The former seeks to obtain the richest ore for the furnace, knowing it will afford the greatest weight of metal for the smallest consumption of fuel and flux, and that a ton weight can be reduced as quickly, and somewhat more cheaply, than a corresponding weight of poor ore. The miner, not always aware of these circumstances, but attracted by the desirability of lessening transport and smelting charges, frequently insists on high percentage ore dressing, that is, of enriching the ore to the exclusion of most of the earthy matter, without estimating the loss of metal which is thereby entailed. A simple illustration will show that the loss of metal occurring in the dressing process *must* be considered and taken into account, if the object is to obtain the greatest money value for the ore contained in the original stuff.

Example.—Take a pile of stuff, containing carbonate of copper, say 2,000 tons, assay 2 per cent., and let 1,000 tons be dressed to afford ore containing 20 per cent. of metal and 1,000 tons treated in like manner to yield a pile of ore assaying 30 per cent. of metal. Dressing cost 30s. and 40s. per ton of ore respectively, transport and smelting cost or "returning charges" 90s. per ton of ore.

Stuff 1000 tons at 2 per cent. = 2000 units.		Stuff 1000 tons at 2 per cent. = 2000 units.	
Dressed to afford 50 tons of ore at 20 per cent.	1000 units.	Dressed to afford 25 tons of ore at 30 per cent.	750 units.
Loss of ore . .	1000 "	Loss of ore . .	1250 "

RELATIVE VALUE OF EACH PILE OF ORE.

50 tons = 1000 units at 16s. . . .		£800 0 0		
Dressing 50 tons at 30s.	£75 0 0			
Returning charges at 90s.	225 0 0			
		300 0 0		
		£500 0 0		

25 tons = 750 units at 16s. . . .		£600 0 0
Dressing 25 tons at 40s.	£50 0 0	
Returning charges at 90s.	112 10 0	
		162 10 0
		437 10 0
Loss on pile of 30 per cent. ore .		62 10 0
		£500 0 0

In this example, although the dressing and returning charges of the richer ore (£162 10s.) is only a little more than one-half of that debited to the 20 per cent. ore, yet the loss of money arising from the extra loss of metal in obtaining the 30 per cent. is £62 10s. In such a case it is clear that the stuff should be enriched so as to afford ore of the lower, and not of the higher metal percentage.

As the necessity for sizing and classifying the smaller size of vein stuff (crusher or stamps work) for the purpose of concentrating the ore grains which it may contain has been adverted to, it will be desirable to define very briefly the meaning of certain terms employed in connection with this division of ore-dressing.

Stuff.—By the term "stuff" is meant an admixture of grains of ore and gangue, such as is obtainable from the crusher-rolls and stamps, and from the operation of jigging, buddling, or other like operation.

Dimension of Grains.—The dimensions, or diameters, of grains of ore and gangue are determined by the sieve or classifier, and are usually expressed in open terms, O to X, the first term, O, including grains of a minimum, and the second term, X, grains of a maximum, diameter. For example, if the minimum diameter of a set of the grains is known, say 2 mm., and the maximum not known, the expression would be, 2 mm. to X, while if the maximum diameter is known, say 10 mm., and the minimum unknown, the converse expression would be used, viz. O to 10 mm.

Spheres and Grains.—The term "grains" is used in a sense synonymous with spheres, from the fact that the holes in a trommel are usually round, and that a sphere is an absolute figure; but grains of ore and gangue are never round, but more or less irregular. At best they only approximate to the figure of a sphere, the limit of approximation depending essentially upon the structure or crystalline character of the minerals themselves.

Sizing.—Sizing consists of passing grains of stuff through a sieve, by which a group of grains are obtained of equal volume (approximately), but of different densities (volumetric sizing).

Classification consists of subjecting grains of different densities to the action of a current of water, when a group of grains, differing in their volumes but having equal velocities of fall (equivalents), are obtained.

Grains from Sieves and Classifiers.—Volumetric grains, or metalliferous and mineral grains, of equal volume, but of different densities, falling through water will separate from each other; in other words, one will fall more rapidly than the other, whereas equivalents, or grains, which will differ from each other in volume and density, will fall in a current of water with equal velocity, and group themselves together at the bottom.

If such grains, having an equal velocity of fall in water and different diameters be placed on a slightly inclined table (buddle or frame), and exposed to the propelling action of a current of water, it will necessarily follow that grains of the larger diameter will expose greater amount of surfaces to the stream than grains of lesser diameter and greater weight. The former will, therefore, move more rapidly than the latter, and a separation of the former will consequently be effected.

Sizing Minerals.—When the separation of mineral substances is to be effected by the medium of water, trommels and classifiers must usually be employed. The trommel is a round cylinder or conical-shaped drum, perforated with holes, and is used for *volumetric* sizing, that is for dividing rough stuff and coarse grains into groups of equal volume but differing from each other in their density, while the classifier—a cylinder box or trough—deals with grains of fine sand and slime, and resolves these grains into "equivalents" or grains differing from each other in their volume but falling through water with equal velocity. The rule for determining the relative volume of grains of different densities, having the same velocity of fall in water, is found by deducting the equivalent of water from the specific weight of the substance and dividing the less into the greater. The density of tinstone may be assumed to be 6 and that of the gangue 2·5. The remaining gravity, when submerged in water, for tinstone is 5, and for the gangue 1·5, therefore a sphere of a diameter 3·3, consisting of gangue, falls at an equal rate in

water with a sphere of tinstone of a diameter of $1 \left(\frac{d-1}{d(1)-1} = \frac{6-1}{2.5-1}\right) = 3.3$. Or, suppose a pile of stuff to consist of galena, blende, and quartz, what will be the relative diameters of the grains having an equal velocity of fall through water?—

		Diameter of Grains having equal Velocity of Fall through Water.
Galena Blende	$7.5-1 = 6.5$ $4.0-1 = 3.0$	Thus $\frac{6.5}{3.0} = 2.1$, or galena 1 diameter, blende 2.1 diameter.
Blende Quartz	$4.0-1 = 3$ $2.6-1 = 1.6$	$\frac{3.0}{1.6} = 1.88$, or blende 1 diameter, quartz 1.9 diameter.

The theoretical reasons for sizing stuff before submitting it to the enriching machinery may be given in the following terms. If bodies of various forms, sizes, and densities be permitted to fall in water in a state of rest, they will experience a different amount of resistance, and consequently not arrive at the bottom at the same time. The resistance which a body experiences in moving through a liquid does not depend on its specific gravity, but solely on its form and extent of surface which it presents to that medium. Supposing we have bodies of the same size and form, differing only in specific gravity, they will all experience the same resistance or lose the same amount of moving force, this loss being proportionately greater on lighter bodies than on those of a higher specific gravity, consequently the latter will arrive at the bottom first. If, on the other hand, we suppose that the bodies differ only in size, it is evident that the larger pieces will arrive at the bottom first, because the resistance is regulated by the squares of the dimensions of the surfaces exposed, while the moving force is proportionate to their cubes. Hence it will be seen that the particles to be jigged should be as nearly as possible of the same size, for the smaller surface of one grain in proportion to its weight will, in a measure, compensate for the greater density of another, and cause it to take up a position to which, by its constitution, it is not entitled. The proportion between the maximum and minimum sizes of the stuff to be operated on should be as the specific gravity of the minerals contained in it.

TABLE SHOWING THE FALL OF SPHERES IN WATER IN ONE SECOND OF TIME, THE LENGTH OF ALL BEING IN MILLIMETRES.

Diameter Millimetres.	Gold. Specific Gravity 19·2. Millimetres.	Galena. Specific Gravity 7·5. Millimetres.	Blende. Specific Gravity 4·0. Millimetres.	Quartz. Specific Gravity 2·6. Millimetres.
17·43	2614	1570	1066	780
11·32	2197	1320	898	653
8·71	1849	1110	750	550
6·16	1569	935	624	461
4·36	1307	785	514	385
3·08	1097	660	448	326
2·17	340	555	378	275
1·54	780	465	317	231
1·08	653	393	266	194
·77	548	327	210	163
·54	456	275	188	137

Let it be supposed that it is necessary to know the relative velocities of fall in water of grains of gold, galena, blende, and quartz, each 1·08 millimetre diameter. An inspection of the table shows the fall of gold to be 653

millimetres per second; galena, 393; blende, 266; quartz, 194. Then let it be assumed that the diameter of the grains vary, the foregoing table will show that gold of 6 millimetres would settle at bottom at the same instant as grains of galena 17·4 millimetres diameter, and that grains of galena 3 millimetres diameter would fall at about the same velocity as grains of quartz $11\frac{3}{10}$ millimetres diameter.

If, further, it be supposed that the grains varied between 8·71 and 17·4 millimetres diameter, some time would elapse, after gold of 8·71 millimetres had settled, before the galena would deposit itself. With blende, however, of 8·71 millimetres, and quartz of 17·43 millimetres diameter, the grains of both would appear at the bottom almost at the same instant.

TABLE SHOWING THE FALL OF SPHERES OF VARIOUS DIAMETERS IN LINES DURING AN EQUAL UNIT OF TIME, THE DEPTH BEING IN INCHES.

Diameter in Lines	Gold. Specific Gravity 19·2.	Galena. Specific Gravity 7·5.	Blende. Specific Gravity 4·0.	Quartz. Specific Gravity 2·6.	Coal. Specific Gravity 1·4.
	Inches.	Inches.	Inches.	Inches.	Inches.
8	100	60·003	40·825	29·814	12·910
5·657	84·090	50·532	34·329	25·071	10·856
4	70·711	42·492	28·868	21·082	9·129
2·828	59·460	35·731	24·275	17·728	7·676
2	50	30·046	20·412	14·907	6·455
1·414	42·045	25·266	17·165	12·535	5·428
1	35·355	21·246	14·434	10·541	4·564
0·707	29·730	17·866	12·137	8·864	3·838
0·5	25	15·023	10·206	7·454	3·227
0·354	21·022	12·633	8·582	6·268	2·714
0·25	17·678	10·623	7·217	5·270	2·282
0·177	14·865	8·933	0·069	4·432	1·919
0·135	12·500	7·512	5·103	3·727	1·614

Were a sieve, partly charged with grains of different minerals, plunged down say 20 or 30 feet in water, the various grains would arrange themselves according to their several velocities of fall, one over the other, assuming them to be of uniform size. Supposing the grains to vary in size, while a sphere of gold eight lines in diameter is falling 100 inches, the grains of galena of the same size will fall 60 inches, blende 40·8 inches, and quartz 29·8 inches. But while the sphere of gold eight lines in diameter is falling 100 inches, one of two lines in diameter will fall only 50 inches, or half as fast as the sphere of the same substance with four times the diameter. Further, a sphere of gold 0·707 lines in diameter will fall about as fast as one of quartz with a diameter of eight lines, or one of galena two lines in diameter, and so on. It thus becomes evident that the velocity of fall of substances in water depends not only upon their specific gravity, but upon their bulk and gravity combined, and that, for a perfect separation of substances according to their gravity, it is essential that the particles should either be of the same size, or that the variation must be confined within certain well-defined limits. As a rule, therefore, the proportion between the maximum and minimum sizes of the stuff to be operated on should be as the specific gravity of the one to the other, the equivalent of water for the sphere being deducted in each case from its specific weight thus:—

Gold and Galena	6·5 :	·18 ::	1 :	2·769
Galena and Blende	3·0 :	6·5 ::	1 :	2·167
Blende and Quartz	1·6 :	·3 ::	1 :	1·88

But to allow for irregularities in practice the proportion of the size of trommel-holes 1 : $\sqrt{2}$ may be taken.

TABLE SHOWING THE TIME REQUIRED FOR THE FALL OF STAMPED STUFF OF DIFFERENT MINERALS AND OF DIFFERENT DIAMETERS.

Size of Stuff in Millimetres.		Galena. Gravity 7·56.	Pyrites. Gravity 4·60 to 5·00.	Barytes. Gravity 4·50.	Blende. Gravity 4·15.	Quartz. Gravity 2·70.	Carbonate of Lime. Gravity 2·60.
From.	To.	Seconds.	Seconds.	Seconds.	Seconds.	Seconds.	Seconds.
30·00	18·00	0·90	—	—	—	2·36	—
18·00	7·00	1·11	—	—	—	3·67	—
7·00	5·50	1·50	—	—	—	4·61	—
5·50	4·44	1·84	—	—	—	6·10	—
4·44	4·17	2·03	2·54	2·81	2·88	7·27	3·86
3·94	3·67	2·48	3·43	3·73	4·61	7·61	5·56
2·77	2·50	3·11	4·41	5·55	6·53	—	6·83
1·77	1·50	4·14	6·21	8·30	9·78	—	10·17
	1·00	5·27	10·36	11·33	11·67	14·64	17·21

Classifying Minerals.—The coarser portions of sand may be sized by means of trommel, but usually for finer sand and slimes a different description of apparatus is employed. In this instance a classification of the equivalents is first effected, and afterwards the ore grains are concentrated together. The following are the principles affecting the classification by the means to be described.

In an horizontal current of decreasing velocity, the larger equivalents introduced will be deposited first, diminishing in size in an equal ratio with the lessening velocity, till, with but a very slight flow, even the finest slimes will be deposited.

A stream rising vertically with decreasing velocity carries the smallest equivalents first away, and only the larger ones remain, while, in proportion to the diminishing velocity of the stream, the finer and finest particles will eventually be deposited.

Horizontal Classifier.—For classification of the equivalents according to the first principle, launders with progressively increasing sections might be employed, in which, first, the largest, and, in the last, the smallest equivalents would be deposited and collected, but for the further treatment the influx would have to be suspended while the various divisions were being completed. To obviate this the launders should be constructed with inclined sides, and provided with a small opening at the bottom to allow of the efflux of the classified stuff.

In the construction of the horizontal classifiers the following rules should be adhered to:—

The width of the first division should be one-tenth of a foot for each cubic foot of slime water introduced per minute, and the following divisions should increase in geometrical progression, thus: 1, 2, 4, &c. The length of the first division is usually taken at 6 feet, and increased in arithmetical proportion, thus: 6, 9, 12, &c. The inclination of the sides should be 50°.

The Vertical Classifier.—The following is the adaptation of the second principle:—

The slime water is conducted into the upper portion of a tank, which is subdivided into three, four, or five divisions, so that an alternate ascending

and descending current is caused. The velocity of this current is diminished by increasing the area of each succeeding division, and according to the principle the larger equivalents are deposited according to the number of subdivisions.

Division of Stuff for Dressing Purposes.—Rittinger adopts one millimetre in diameter as the unit of holes for sizing ores for concentration, and the progression beyond this is geometric, as 1, 2, 4, 8, 16 millimetres, giving for the volumes of the grains that will pass the holes respectively 1, 8, 64, 512, 4,096 cubic millimetres. He divides each of these sizes into four classes, each with four grades, thus:—

	Diameter in Millimetres.		In Inches nearly.	
No. 1. Rough Stuff	64·0	=	2·51	coarse.
	45·2	=	1·79	middling coarse.
	32·0	=	1·26	„ fine.
	22·6	=	0·89	fine.
No. 2. Coarse Stuff	16·0	=	0·63	coarse.
	11·3	=	0·45	middling coarse.
	8·0	=	0·319	„ fine.
	5·6	=	0·220	fine.
No. 3. Coarse Sand	4·0	=	0·160	coarse.
	2·8	=	0·109	middling coarse.
	2·0	=	0·078	„ fine.
	1·4	=	0·055	fine.
No. 4. Fine Sand and Slime	1·00	=	0·0400	coarse.
	0·71	=	0·0282	middling coarse.
	0·50	=	0·0200	„ fine.
	0·35	=	0·0137	fine.

The divisions adopted by Darlington for the purpose of dressing lead and copper ores are of a more simple kind. He reduces the stuff by means of crushing-rolls to sizes varying from 0 to 7½ millimetres. These are subdivided into—

		Mil.		Mil.	
No. 1.	Rough Stuff	5	to	7½	Sized for rough jigger.
	„	3½		5	
No. 2.	Coarse Sand	2		3½	„ coarse jigger.
	„	1¼		2	„ „
No. 3.	Fine Sand			1¼	Classified for fine jigger.
					„ buddles or frames.
No. 4.	Coarse Slime				
	Fine „				

For tin-dressing Darlington suggests the following classifying arrangement:—

1. Place in front of the stamps a properly-constructed classifier, either an horizontal gradually widening launder (Spitzkasten) or a series of V-shaped boxes, each proportioned in its dimensions to the work to be done.
2. Treat each classified product directly in jiggers or upon round buddles or frames.

Metric System.—The metric system is now mostly in use throughout Europe. In referring this system to the dressing of ores the metre for *space unit* is used as the standard of velocities, while for the *unit of time* the second is employed. As the metric scale of measurement admits of a closer expression of the relative size of one grain of sand with that of another than the ordinary division of the inch, the word "millimetre" will frequently occur. An inch is represented by about 25 French millimetres or by 12 Prussian or Austrian "lines."

The length of a metre is 39·3708 English inches, and is divided into—

1 Metre (m.)	= 1	metre or	1	or 39·3708	inches		
1 Decimetre	= 0·1	,,	$\frac{1}{10}$	,, 3·93708	,,	or 4 inches nearly	
1 Centimetre (cm.)	= 0·01	,,	$\frac{1}{100}$	,, 0·393708	inch	,, $\frac{4}{10}$ or $\frac{3}{8}$ inch nearly	
1 Millimetre (mm.)	= 0·001	,,	$\frac{1}{1000}$	,, 0·0393708	,,	,, $\frac{4}{100}$ or $\frac{1}{25}$ inch nearly	

Axioms of Dressing.—(1.) Absolute perfection in separation according to specific gravity cannot be arrived at chiefly on account of the irregularity of form of the various grains to be operated upon.

(2.) The more finely divided the stuff to be treated, the greater the amount of labour and care does the stuff require, and the more imperfect is the separation.

(3.) That reducing machine may be considered the most perfect which produces the least quantity of smaller stuff than the size intended to be produced.

(4.) The value of limiting the degree of fineness to which a mineral should be reduced at first, is that a proportion at least of the deads, as also a portion of clean ore, will be obtained by the first operation of jigging, thus saving valueless application of labour and power in the reduction of the former, and preventing loss on a more minute subdivision of the latter. In the case, therefore, of grains of ore of considerable size being contained in the mineral to be treated, a waste, which would infallibly occur in the treatment of them after a finer division of the same, is avoided, while, should the proportion of matrix preponderate, a considerable quantity of waste is at once withdrawn from the labour and expense consequent on its reduction.

As a general rule, therefore, the mineral to be treated should at first only be reduced to that size which will allow of the separation of a portion of the ore contained, or of the deads, should these be in a large proportion. To what extent the finer reduction of the resulting middles or mixed ore and matrix should be carried is dependent on the same principle as that already given for the reduction of the mineral stuff, as also on the difference between the specific gravity of the ore and the various other components of the mineral substance.

As regards the separation of the reduced mineral, the following may be assumed:—

(1.) That apparatus or plan of dressing may be considered as most efficient which, with stuff of a given average size, allows with equal cost of a more perfect separation of stuff of a nearer equal specific gravity. For, the average percentage to which the crop is to be brought, and the highest percentage to be allowed in the castaways being determined, it is evident that the more perfect the degree of separation, the greater will be the amount of crop and castaways obtained at each operation, and the quantity of middles or stuff to be re-worked will be diminished. Thus, in the same manner as was remarked in the observations on reduction, useless expense and loss of ore will be avoided.

(2.) We may further consider, as a great improvement in dressing operations, such apparatus or plan of working which will allow, without a disproportionate increase in the cost, of the equally perfect separation of fine stuff, as that of the coarser, as now practised. This will be of especial benefit in

the case of finely disseminated ore, which is obliged to be reduced to a great degree of fineness.

Moisture in Ores.—The amount of moisture in ores sampled for sale within the ordinary period after completing the dressing operation varies with the constituents and size of the particles of which the pile of ore is composed.

Lead Ore.—The following figures are derived from a se results:—

	Cwm Erfin, per 21 cwts.	= 76 lbs. of water	= 3·2 per cent.
	East Daren ,,	= 64 ,,	= 2·7 ,,
	Goginan ,,	= 102 ,,	= 4·3 ,,
	Lisburne ,,	= 64 ,,	= 2·7 ,,
	Cwm-ystwyth ,,	= 54 ,,	= 2·2 ,,
	Minera ,,	= 28 ,,	= 1·25 ,,
	Average per 21 cwts.	64	3·69
Blende.	Minera . . .	68 lbs. of water	= 3·00 per cent.
Oxide of Tin.	Wheal Agar per 20 cwts.	130 ,,	= 5·80 ,,
	Wheal Basset . .	158 ,,	= 7 ,,

The weight of a cubic foot of dressed lead ore will vary—(1) with the quality of the ore, whether it may be solid or spongy in its structure; (2) if free from earthy matter; (3) if the grains may be coarse or fine, or much charged with moisture. Some varieties of fine grain silver lead ore cannot be advantageously enriched to afford more than 50 to 55 per cent. of lead, while heavy, pure, and compact galena may be dressed to yield 73 to 76 per cent. of metal.

TABLE SHOWING NUMBER OF CUBIC FEET IN A TON OF DIFFERENT VARIETIES OF ORE.

	Mines.	Assay.	Cubic Feet to a Ton of Ore
Galena.	Esgair-hir—dressed ore . . .	73 per cent. of metal .	9
	Minera ,, . . .	75 ,, . . .	$8\frac{3}{10}$
	Ballacorkish ,, . . .	70 ,, . . .	10
	Wildberg—cobbed, dressed ore .	52 ,, . . .	10
	sieve raggings . .	50 ,, . . .	11
Silver Ore.	Hiendelaenncina—silver ore . .	. . . . . .	$10\frac{1}{2}$
Blende.	Minera	. . . . . .	14 to 15
Oxide of Tin.	Wheal Agar	70 ,, . . .	$9\frac{3}{10}$
	Wheal Basset	70 ,, . . .	$9\frac{9}{10}$

DRESSING MACHINERY AND APPARATUS.

The machinery and apparatus employed in the mechanical concentration of ores may be grouped under the following heads:—

(A.) Dressing Tools.—Shovels, Hammers, Barrows, Trays, and Forwarding Apparatus.
(B.) Washing Apparatus.—Kilns and Washing Trommels.
(C.) Reducing Tools and Machinery.—Slides, Ragging Spalling, Stone-breakers, Crushing Mills, Stamps, and Pulverisers.
(D.) Sizing Apparatus.—Riddles and Trommels.
(E.) Classifying Apparatus.—Classifying Troughs and Cones.
(F.) Jigging Machines.—Sieve, Lever, and Continuous Jiggers.
(G.) Buddles and Tables.—Strips, Round and Concave, Buddles, and Frames.
(H.) Calciners.—Brunton's and Hocking's Calciner.
(J.) Humid Processes.—Longmaid Duclos, Oxland, Henderson, Claudet.
(K.) Magnetic Separators.—King's Machines.
(L.) Tossing and Packing.
(M.) Sampling Ores.—Lead, Copper, and Tin.
(N.) Dressing Ores.—Lead, Copper, and Tin.

(A.) The dressing tools and appliances used are but few in number. As they differ in some respects from the mining tools described on page 654, a

short description is required. The *shovel*, of a triangular shape, is made of good hammered iron pointed with steel. The dimensions of shovels vary, but one of an average size is about 11 inches wide at the top and 13 inches from the point to the shank, weight 4 lbs., cost one shilling, to which must be added fivepence for the handle. The handle should be of best cleft ash, free from knots and slightly curved. A *vanning shovel* is 14 inches long and 13 inches wide at the top. It has a finely-graded hollow for the purpose of retaining the vanned ore. *Mallets* are made of cast steel or rolled bar-iron. If of the latter material, the eye must be punched across the grain. Many forms of different weights are in use. *Picks* are of various dimensions and weights. The Cornish "Poll" pick weighs 4½ lbs. The head, which is 17¾ inches long, is fitted with a handle 26 inches long. The *sledge* used for breaking or "ragging" rocks weighs from 6 to 8 lbs., while the spalling hammer, made of cast steel set upon a thin pliant handle, weighs only 1 lb. *Picking boxes*, for collecting prill or dredge ore, are made of deal plank 1 inch thick. The ordinary dimensions of a box are—length, 16 inches; depth, 7 inches; width at bottom, 7 inches, and at top, 10 inches. Ledges of wood to serve as handles are frequently nailed to the ends of the box. *Wheel-barrow.*—The sides, ends, and bottom are made of deal plank 1¼ inch thick. The ends are morticed to the sides, and the bottom fastened by means of nails. The upper edges of the sides and ends are protected by strips of hoop-iron, while short pieces of hoop-iron are used for strengthening the corners. The wheel, frequently made of wrought iron ⅝ inch round, is 14 inches diameter. The length of the sides of an ordinary barrow is 60 inches, depth at centre 9 inches. *Hand-barrow.*—At surface, particularly for weighing and shifting ore, a hand-barrow is generally employed. This barrow is provided with handles at each end. The plank of which it is made is 1¼ inch thick; length of sides, 66 inches; depth at centre, 9 inches; width at top, 18 inches; at bottom, 10 inches; length at top, 24 inches; at bottom, 18 inches. *Tramways.*—The gauge of surface tramways varies from 15 to 30 inches. Ordinary bridge rails are usually employed; but where iron is dear and timber cheap, a serviceable rail may be formed of a runner, a strip of timber 2 inches square, and a strip of iron 1½ by ¼ inch thick, laid upon the latter, and fastened with nails or screws. *Tram-waggon.*—The tram-waggon is generally constructed of sheet iron with wrought-iron axles and light steel wheels. The capacity of a waggon is mostly an arbitrary one. *Dipper-wheel.*—Stamped ore, and water heavily charged with slime, are commonly lifted from a lower to a higher elevation by a dipper-wheel. This apparatus consists of a wheel 15 or 20 feet diameter, with a wooden rim, to which are attached sheet-iron buckets. These buckets, in their rotative movement, scoop up, lift, and empty, stamped or slime ore to the height required. Stuff consisting of slimes and sand may also be readily lifted from one point to another by means of a raff-wheel, Jacob's ladder, or Archimedean screw. *Circulating pump.*—Few mines of importance in the central part of Cornwall possess an initial volume of water sufficient for dressing purposes. To overcome this drawback a circulating pump is employed. In most cases it consists of a simple plunger attached to an engine. At Wheal Basset the circulating pump in connection with eighty heads of stamps and adjacent

dressing appliances is 15 inches diameter and 9 feet stroke. This plunger forces about 800 gallons of water per minute to a height of 60 feet, requiring about 14 horse-power to do the work.

(B.) *Washing Apparatus.*—The vein stuff, on arriving at the surface, is not only often associated with a large amount of gangue, but is frequently much intermixed with clay, rock, and silicious matter.

In order to get rid of the latter substances it is usually washed and picked. The washing apparatus ought to be so contrived as to allow the cleansing to be effected both cheaply and expeditiously, and for this purpose an ample volume and fall of water is always desirable. In accordance with the character of the ore the apparatus will have to be varied; but for lead, certain varieties of copper ore, as well as for iron or other abundant ores, the wash-kiln will be found satisfactory. In many mines a rectangular grate is fitted to the bottom of the kiln; but a perforated plate would be found to furnish better results, since the former allows of the passage of flat irregular pieces of stone, rendering their treatment in the jigging sieves less successful. The holes in the perforated plate should be conical, the largest diameter underneath, so that the stones may have a clearance-way. In connection with the kiln-plate a sizing trommel should be used, and in order to economise both time and expenditure it would be judicious to introduce the vein stuff and discharge the castaways by means of railways.

The picking of the stuff is an important operation. As a rule all picked ore should be selected, and the dredge deprived of the largest possible amount of waste before it is sent to the crusher. It is fallacious to suppose, because machinery will deal with large quantities of stuff expeditiously, that it will be cheaper to subject the mass to its action; on the contrary, if correct calculations are made of the losses ensuing on the initial quantity of ore before the residue is ready for the pile, the cost of the several intricate manipulations requisite to get rid of the castaways, and of the wear and maintenance of machinery, it will appear in the greater number of cases that the more profitable method will be to incur an extra first charge in order to reject the sterile portion by means of hand labour. The ragging-hammer should therefore be brought into free requisition, and all worthless stones at once rejected; then in spalling such portions as have been ragged, an additional quantity of refuse should be excluded, whilst in the process of cobbing either ragged or spalled work, the greatest care and attention should be given in order to bring the dredge to a maximum degree of richness.

Wash Kiln.—In the lead mines of the North of England and Wales the vein stuff as it comes from the mines is usually deposited in a receptacle known as the kiln. This apparatus usually consists of a hopper—constructed of wood or masonry—an opening at the bottom, a grate or perforated plate, and a collecting-box set underneath the plate. Also of a water launder placed above the kiln. The stuff deposited in the kiln is subject to the action of a stream of water falling from the launder and of a rake used by a kilnman, who stands immediately in front of the grate. The effect of the grating operation is, therefore, to free the stuff from clay, and to separate the former into two classes:

(1) *Roughs.*—Stuff too large to pass through the holes of the grate and to be picked into.

(*a*) Prill, or clean ore.
(*b*) Dredge ore for cobbing.
(*c*) Waste for hillock.

(2) *Smalls.*—Stuff passed through holes in the grate and to be jigged so as to afford

(*a*) Clean ore.
(*b*) Raggings (dredge work) to be reduced in crusher, and subsequently jigged.
(*c*) Waste for hillock.

With this cheap and simple apparatus, usually the first stage in copper or lead ore dressing, satisfactory results are obtained. In a single kiln twenty tons of stuff may be grated in a day of ten hours, at a cost of less than 4d. per ton.

The following are actual results of kiln-washing :—

Capacity of kiln, 20 tons.
Time required to grate 20 tons, one man, 10 hours.

	s.	d.	
Kiln-man	2	6	per day.
Throwing roughs "on picking-table," one boy	1	6	,,
Delivering "fine stuff" to jiggers, one boy	1	6	,,
	5	6	

$\frac{5/6}{20} = 3\frac{3}{10}$d. per ton.

Washing Kiln and Sizing Trommel.—Fig. 192 represents an elevation of

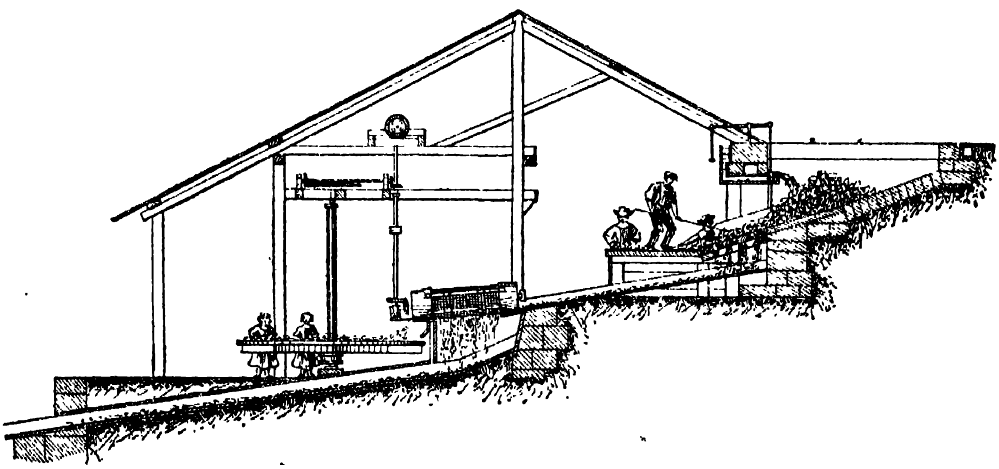

Fig. 192.

this arrangement introduced some years ago at the Frongoch mine, Cardiganshire. The kiln is a semi-elliptic structure of masonry, with an inclined bed, at the foot of which is set an inclined grate; a launder supplies water for washing purposes, while a man with a rake grates and distributes the roughs to girls who stand around the tables. In this operation the stuff is picked into

Prill, or clean ore.
Dredge ore to be "*cobbed*" or crushed.
Waste for the hillock.

The rough smalls, which have passed through the grate, now go to the trommel, where it is further divided into

Rough smalls for the rotating picking-table, which are picked or subdivided by the girls into prill, dredge, and waste, and *Fine smalls* for the jigging-sieves.

The dimensions of the kiln are—

Width at top from grate to back	9 feet 0 inches.
Top length at back wall	12 " 0 "
Length at back of grate	4 " 0 "
Depth at back wall	1 " 6 "
Depth at grate	4 " 6 "

The front wall of the kiln is 2 feet thick. The grate, $3\frac{1}{2}$ feet long, fixed on timber, 5 inches by 6 inches and 5 feet long. This grate is cast with bars $1\frac{1}{4}$ inch thick at top and $\frac{1}{2}$ inch thick at bottom. The open space between the bars on the upper side is $\frac{7}{8}$ inch, and on the under side $1\frac{5}{8}$ inch; the picking-table partly surrounding the grate is $6\frac{1}{2}$ feet long, 8 feet wide, and is set $2\frac{1}{2}$ feet from the ground; the dividing trommel is $5\frac{1}{4}$ feet long, and 1 foot 5 inches diameter. It has a fall of 4 inches in this length, and is speeded at 40 revolutions per minute. The rotatory picking-table, 10 feet diameter and 22 inches high from the ground, makes every four minutes one revolution, or a circumferential speed of $7\frac{1}{2}$ feet per minute. The hands usually required in connection with this apparatus are—a man to grate and distribute the stuff; four girls, two on each side of the table, to pick the stuff; and four small girls at the rotating table. Men or strong boys are employed to remove the waste to the hillock, the quantity of waste varying with the proportion which may be associated with the stuff delivered to the kiln.

Washing or Clearing Trommel.—The washing or clearing trommel is employed in many places instead of a washing kiln. Its use depends upon the existence of large quantities of argillaceous vein stuff necessitating cheap and rapid despatch; thus the clearing trommel is frequently adopted for enriching iron and zinc ores, phosphate of lime, and minerals of low value. The cylinder is commonly parallel with the axis. In some instances, however, it takes the form of a double cone, the larger diameter of one end being united to that of the other. When the shell is strictly cylindrical in its form, angle or T iron is fastened to the inside for the purpose of lifting and dropping the stuff; but when conical, the stuff is either washed and delivered by an Archimedean screw or by an arrangement of wrought-iron buckets similar to those fitted to an ordinary raff-wheel. In cases where rock veinstone is first rejected or reduced to a comparatively small size, the clearing trommel may be furnished with one or more sizing cylinders, for the purpose of dividing the stuff into fine and coarse sand for jiggers and rough work for the picking table or crusher. Washing trommels may be constructed of wood or iron; the latter is, however, the better material, except when acidulated water prevails.

For the construction and working of wash trommels the following general particulars are given:—Diameter of trommel, from 4 to 5 feet; length, 9 to 10 feet; angle of conical shell for ordinary vein stuff, 1 inch per foot; for clayey stuff, $\frac{1}{2}$ inch per foot; number of revolutions per minute, 10 to 15; water required, from 10 to 30 gallons per minute; quantity of ordinary "small" vein stuff washed per hour, 6 to 10 tons; dirty clayey stuff, 3 to 5 tons; power required per trommel, from one-half to three-quarters of a horse.

:.) *Reducing Tools and Machinery.*—In removing portions of a vein underground, rocks are broken in which valuable ore is more or less disseminated. The vein stuff, enclosing oxide of tin, copper pyrites, or galena, on arriving at surface is usually deposited in slides or receptacles formed under an elevated tramway. At this point the large stones are ragged by means of a sledge hammer, that is, roughly broken up and the sterile portions rejected. The weight of a ragging hammer is about 12 lbs. If no stone-breaker exists, the ragging operation is succeeded by a spalling process, in which small hammers about 3 lbs. weight are used for reducing the stones for the stamps or crushing mill to about the size of road metal. Since the introduction of a stone-breaker the vein stuff is so effectually broken as to materially diminish the crushing or stamping power which would otherwise be necessary. When vein stuff is reduced to pieces by the spalling hammer its compactness is not in the least affected, and being broken chiefly at the "heads" or joints the stone retains its original texture. In fact, the only effect of hand-spalling is to reduce the rock from large to moderately small pieces. The stone-breaker, on the contrary, crushes up the rock irrespective of joints or faces, and the toughness and texture of the rock is so destroyed that the crushing-mill or stamps can act upon it with far greater effect. Part of the extra efficiency of both mills is due to the fact that the stone, when passing between the rolls or under the stamp heads, is broken very much finer than is the case when hand labour alone is employed. There is no danger of the work of the crusher or stamps being hindered by large stones getting between the rolls or under the heads and impeding their action for some considerable time before they are broken down; whilst, on the other hand, the stamps working on an even bed will be uniformly doing good work. Perhaps the best proof of the difference between the action of the breaker on the rock and the action of the hammer is that the former will produce three tons of fine sand where the latter will produce one. Thus the stone-breaker not only does the actual breaking cheaper than it can be done by hand labour, but at the same time it is doing part of the work which would under other circumstances have to be done by the crusher or stamps. When the crusher-mill is supplied from a breaker, the wear of the rolls or heads is considerably lessened, and the feed may be rendered more regular.

The Stone-breaker.—The general cost of breaking a ton of tinstone by hand and by means of machinery has been estimated by Captain Tregay, late of Peden-andrea, particulars of which are as follows:—

HAND LABOUR.

	Per 100 Sacks, equal 10 Tons. £	s.	d.
Cost of breaking tinstone .	0	6	4
Deduct for dividing do. .	0	1	3
	10) 0	5	1
Or per ton	0	0	$6\frac{1}{10}$

STONE-BREAKER.

	£	s.	d.
Cost of stone-breaker, 20 inches by 9 inches	400	0	0
Alteration of floors	300	0	0
	700	0	0

			£	s.	d.
Interest on outlay at 5 per cent., assuming 50 tons put through breaker per day			Per 100 sacks, equal 10 tons.		
Interest on £700 at 5 per cent.			0	0	$5\frac{1}{4}$
Wear and tear			0	0	4
Coals and grease			0	0	4
Labour cost	3	$3\frac{1}{2}$			
Less dividing tinstone	1	3			
			0	2	$0\frac{1}{2}$
		10)	0	3	$1\frac{3}{4}$
Or per ton			0	0	$3\frac{3}{4}$

Cost by hand labour	$6\frac{1}{10}$d.	per ton of tinstone.	
Do. by stone-breaker	$3\frac{3}{4}$d.	,,	,,
In favour of stone-breaker	$2\frac{7}{20}$d.	,,	,,

The question of the position of the stone-breaker on a mine is of considerable importance The chief object should be to render the dressing process one of an automatic character. No definite rule can possibly be laid down as to the position of the machine; that will in many cases depend on local conditions. At Peden-andrea the stuff drawn to surface is (1) tipped into the tram-waggon and pushed by the lander along a raised tramroad to a point over the stone-breaker floor; (2) the stuff is then shot over a grating, the bars of which are 2 to $2\frac{1}{2}$ inches apart, and the smalls separated from the larger stones before reaching the floor below. Here the latter are picked over, and any pieces too large to go to the stone-breaker are ragged. The breaker is so placed that the stuff can be shovelled direct into the hopper. When the stones are broken the fragments fall upon a lower floor beneath, where the stuff is divided and sampled and thrown into waggons to be conveyed to the stamps. The smalls not requiring to go through the breaker are wheeled to a point over the lower floor, where they are sampled and thrown into waggons below. This arrangement is rendered necessary from the fact that the lode is mostly worked by tributers; hence as each tributer's stuff must be divided and sampled, it is not practicable to allow the tin stuff to fall direct from the stone-breaker into the tram waggons.

In various Australian and American mines, the vein stuff is tipped upon a "grizzley" or slide, the large stones go directly through the stone-breaker and the small stuff through the grizzley bars. Both products then pass together through a shoot set underneath the stone-breaker, into a hopper communicating with the stamps.

If the jaws of a stone-breaker are set 2 to $2\frac{1}{2}$ inches apart at the bottom, the stuff will be delivered from three to four times smaller than by hand-spalling. The size at the opening at the top of the jaws varies with and determines the size of the machine and measures the largest stone that can possibly be dealt with. The weight of stone which can be reduced in a given time necessarily depends upon its hardness as well as upon its structure, and obviously the result may be augmented or decreased according to the distance between the jaws and the speed given to the eccentric shaft; the best speed is from 200 to 250 revolutions per minute.

The following table gives the approximate weight of stone reduced by jaws of various dimensions, also the power required, the eccentric shaft making 200 revolutions per minute :—

TABLE RELATING TO STONE-BREAKERS.

—	Dimensions of Machine at Mouth of Jaw.	Approximate Weight of Stuff reduced.	Nominal Horse-power required.
	Inches.	Cwt.	By Hand.
Stone-grinder	5 × ½		
Do.	6 × 1½	5	2 to 4 Men.
Do.	12 × 3	10	4 ,,
Do.	20 × 3	15	5 ,,
Do.	20 × 5	18	7 ,,
Do.	24 × 6	20	9 ,,
Stone-breaker	7½ × 4	30	1½ ,,
Do.	9 × 6	60	2 ,,
Do.	10 × 8	83	3 ,,
Do.	12 × 8	108	3 ,,
Do.	12 × 9	120	5 ,,
Do.	15 × 8	125	5 ,,
Do.	15 × 10	150	6 ,,
Do.	18 × 9	175	7 ,,
Do.	18 × 12	180	8 ,,
Do.	20 × 10	200	8 ,,
Do.	24 × 13	280	10 ,,
Do.	24 × 15	300	12 ,,
Do.	24 × 17	330	14 ,,
Do.	24 × 19	350	16 ,,
Do.	30 × 13	350	16 ,,
Do.	30 × 15	370	16 ,,
Do.	30 × 18	400	18 ,,
Do.	24 × 24	400	18 ,,
Do.	30 × 24	460	20 ,,

Both the movable and fixed jaw of a stone-breaker should be of double-chilled iron. The use of soft or badly-hardened iron is highly objectionable, since it will impose serious delays in withdrawing and replacing the pieces, and increase the cost of reducing the stone. A pair of good jaws 12 inches by 9 inches will cost about £3, to which must be added £1 10s., the cost of taking out old and putting in new jaws, or a total of £4 10s. A bad pair of jaws will not break 300 tons of stone, while a well-hardened pair will break from 2,000 to 3,000 tons of silicious veinstone. In some dressing works sizing trommels are placed under the stone-breaker, in others flat sizing sieves are reciprocated by a rod attached to the movable jaw. The stuff is also in some instances discharged on rotating or fixed tables, or on travelling bands constructed on the principle of a coiling window shutter.

Fig. 193 shows sectional elevation of an ordinary stone-breaker as constructed by Marsden & Co., of Leeds. A, main frame; F, fly-wheel shaft, which should make about 250 revolutions per minute by means of the belt from the engine on to pulley, Q. The larger circle enclosing F shows the eccentric. H, vertical rod connecting the eccentric with the toggle-plates J and K, which have bearings forming an elbow or toggle-joint. These bearings, it will be seen, are renewable, and the same may be said of all the pillows and bearings throughout the machine. C is the cotter for taking up the wear of the pillow or bush in which the eccentric works in the connecting-rod head; I is the cotter for keeping securely in their places the bearings of the toggle-plates; B is a false back accurately planed on the surface and bedded to the frame A; C 1, 2, 3, and 4 are jaw-faces, which are fitted with patent metal strips on their backs, and thus find a firm and even bed for themselves, preventing sudden strains which they necessarily have

to encounter, causing them to break and give way; E is the shaft of the swing jaw which is cottered to it, and itself rests upon each side of the main frame A; J is the key for keeping in position the swing-jaw faces C 3 and C 4; D is the swing jaw itself; C 5 is a cheek of which there are two, one on each side of the mouth, and which keep the fixed jaws in position; and

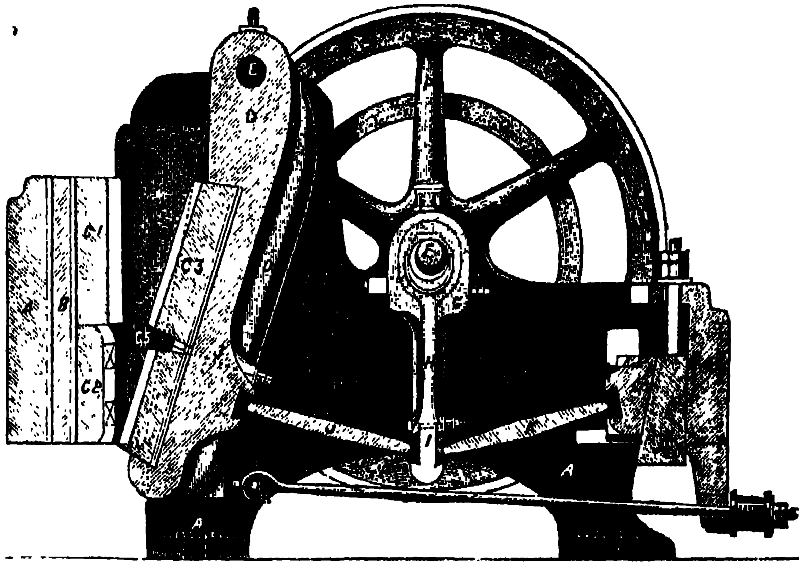

Fig. 193.

prevents the stone from wearing into the sides of the main frame; P is the fly-wheel; L is the toggle-block and wedge. The toggle-block, as will be seen, takes the cushion or bearing of the toggle-plate K, and itself is held in position at one height always by means of lugs on each side of the frame; whereas the wedge L moves up or down at the will of the user of the machine, thus reducing or increasing the opening of the jaw at the bottom, and so regulating the size of the product. The hook-bar underneath the machine has an india-rubber disc attached to it at the end, which is compressed by the forward movement of the jaw and aids its return; every revolution of the eccentric F causes the lower end of the swing jaw D to advance toward the fixed jaw about ½ an inch and return; hence when a stone is dropped in between the jaws it is broken by the next succeeding bite. The fragments then fall lower down and are broken again, until they are small enough to fall out at the bottom. The distance between the jaws at the bottom limits the size of the product, and these distances, as before named, can be regulated at will by turning the screw-nut which raises or lowers the wedge L; greater variation may also be made by substituting for the toggle J longer or shorter ones, furnished for that purpose.

Stone-grinder.—The ordinary stone-breaker has been modified in some of its minor details by the Messrs. Marsden & Co. for the purpose of reducing stone to the condition of sand. A, Fig. 194, is the main frame; T, fly-wheel crank shaft, which should make about 300 revolutions per minute by means of the belt from the engine on to driving pulley Q;

the connecting-rod which connects the crank with the lever C which its bearing on the fulcrum-shaft D; E is the shaft connecting the end of the lever with the top of the grinding jaw B; G is the grinding-jaw face, H is the fixed-jaw face, and each of these faces are fitted with patent metal strips on their backs, thus enabling them to find a solid bed, preventing the great strain they necessarily have to bear, causing them to break; U is the key, of which there are two, one on each side of the mouth, which keeps the fixed jaw-piece in position and prevents the material wearing into the sides of the main frame; N is a wedge which, on being lifted or lowered by means of a screw-key, thrusts forward or allows to recede the toggle-block M and grinding jaw B, thus allowing the jaws to be more or less open at the bottom according to the degree of fineness the product is required to be, and also to take up wear on the jaw-faces; W is the toggle or knuckle-joint plate which allows the grinding jaw free movement, and at the same time keeps it within prescribed limits; R is the bar connecting the spring to the grinding jaw, and which facilitates its receding movement. It will be seen that, at the commencement of every revolution till the centre is reached, the connecting-rod F draws up the end of the lever C, which resting upon its fulcrum shaft D causes the grinding jaw B, which is connected with the lever end by the shaft E, to have a forward and downward grinding motion of immense power upon the material in the mouth between the jaw faces G and H. The toggle-plate W also thrusting forward the lower part of the jaw on the remaining portion of the revolution the exact reverse takes place, and the material operated upon falls into the shoot S, which conveys it into the sieve J. This sieve is fitted with gauze K suitable for the fineness of product required; there are also supporting and protective gauges fitted in every screen, which prevents injury to the finer gauzes. By a raff-wheel arrangement in the interior, all material that will not pass through the finer gauze is carried by the scoops L, and at each revolution of the screen upon spindle I these scoops empty themselves into the hopper O, which conveys their contents into the mouth in conjunction with the regular feed to the machine; thus all the stuff gets ground and reground upon until it becomes of the proper degree of fineness. The advantage of this machine—which has been recently much improved—is, that by a simple adjustment any degree of fineness can be secured.

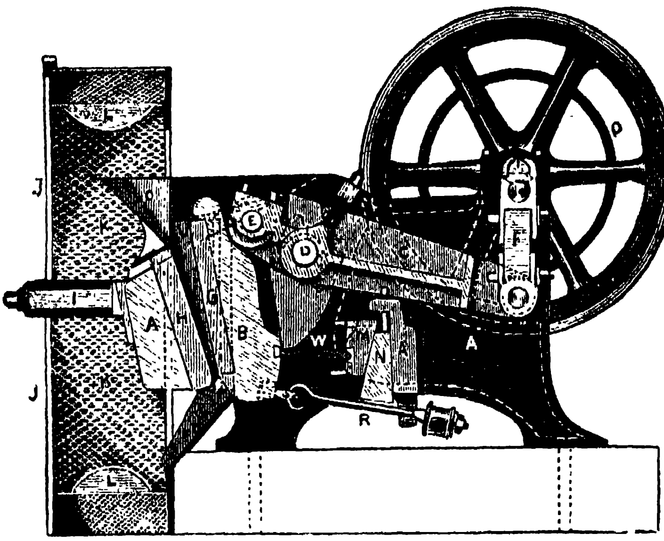

Fig. 194.

Crushing and Grinding Mills.—When copper, blende, or ore is freely intermixed with veinstone the separation of one from the other is commonly effected by crushing the stone, bringing particles of like sizes together, and subjecting the products to the action of jigging-machines, or other suitable enriching apparatus. Long experience has demonstrated the fact that the difficulty of concentrating ore increases with its fineness, consequently it is of great importance to secure the metalliferous grains as near to their natural dimensions as is possible. Whatever practical care may be employed for this purpose, the desired results can be only partially attained, nevertheless a considerable loss in castaways, as well as unnecessary expense in dressing, may sometimes be avoided by properly adjusting the pressure on the rolls, and permitting the crushed stuff to go direct to a slime separator and sizing trommels.

In Cornish mills the rolls, riddle, and raff-wheel arrangement produces a kind of continuous crushing, the "roughs" larger than the riddle spaces being again and again returned to the rolls. In soft copper and lead ore associated with hard quartz and Slate, the result is an unnecessary proportion of fine ore and clay, which in water too frequently forms a viscid and objectionable slime. In Continental mills the raff-wheel and riddle seldom form an accessory to the rolls. The general practice is to maintain the faces of the latter in good condition, and to pass the crushed stuff direct to the sizing trommels, sending only such portion as cannot be jigged either to the first or to a second crusher. Except for the purpose of crushing earthy varieties of coal, the German crusher is, for the same diameter, usually much shorter on the face than those used in this country; in fact, the width of the roll seems to be decreased in an arbitrary proportion with the hardness of the stuff. In addition, the mill is provided with a fly-wheel for preventing irregularity of motion. For crushing fine stuff a feed-roller is frequently geared in connection with the crushing rolls, and the latter are always kept to their work by means of adjustable springs. Disc springs, consisting of alternate plates of india-rubber and iron, have altogether superseded the lever and weight. Rolls subject to the former arrangement merely open sufficiently wide to allow hard foreign substances to pass, but under dead-weight pressure hard resisting material is apt to jerk the levers, and to carry the rolls farther apart than is necessary; thus, with a long irregular line of roller face uncrushed stuff must freely pass to the revolving riddle, be raised and repassed until crushed sufficiently small to escape through the meshes of the latter. The mode of gearing the roll to the axle is also different in German to English practice. A thick cylinder is truly centred on a wrought-iron shaft; and on the outer surface of this cylinder, which is slightly taper, the crusher shell is securely fixed by means of three bolts and nuts.

The rolls of French mills are from 8 to 45 inches in diameter, length on face from 8 to 12 inches. In Germany the length of rolls for crushing metalliferous ore is usually 10 inches long, which are from 10 to 36 inches in diameter. For the purpose of crushing shaly coals the length varies from 20 to 30 inches.

Now that the use of stone-breakers renders it unnecessary to employ rolls

of very large dimensions, coarse jigger work may be advantageously obtained with rolls from 18 to 24 inches diameter, and fine jigger work from rolls 10 to 18 inches diameter.

Rough, coarse, and fine sand jigger stuff cannot be defined with any approach to accuracy; either will naturally vary with the grain size of the ore, and its associated mineral, which is determined principally by the crystalline condition of the earthy and the metalliferous portions. It will be sufficiently near for all practical purposes to regard stuff ranging in size from 3 to 8 millimetres as rough jigger work, sand from 1 millimetre to 3 millimetres as coarse jigger work, and sand from ⅛th to 1 millimetre as fine jigger work.

The cost of reducing a ton of stuff to a given size must depend on a number of conditions, such as cost and hardness of rolls, charges incident to wear and tear of machinery, cost of power, value of labour, structure of the stuff to be crushed, and arrangement of the mill itself. Hard, well-proportioned rolls should always be employed even if moderately economical results are to be obtained. In Germany steel rings have been found to give excellent wear, but the cost of fixing and turning the rings has to a great extent precluded their use. The circumferential speed of rolls in German mills is from 90 to 180 feet per minute. Variable speeds have been tried in order to produce friction, together with pressure at the line of contact; but it has been found that any departure from a uniform speed in the two surfaces absorbs a considerable amount of power without materially augmenting the results. Rollers worked by friction furnish less economical results than those driven by spur gearing.

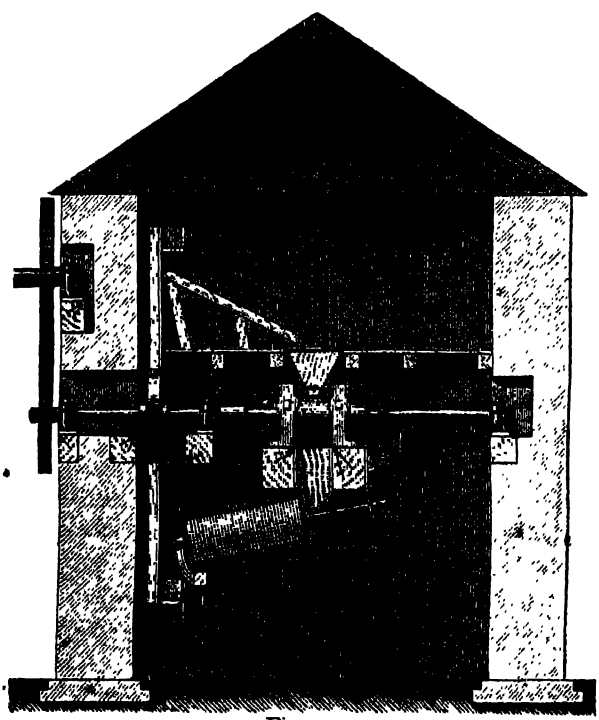
Fig. 195.

The following particulars are given in connection with a Cornish crusher operating on steel grain lead ore, associated with carbonate of iron, quartz, and hard grauwacke:—Diameter of rolls, 21 inches; length on face of rolls, 19 inches; weight of new pair of rolls, 2,700 lbs.; weight of worn-out pair of rolls, 1,600 lbs.; number of revolutions of rolls per minute, 8; speed on face of rolls per minute, 42 feet; size of stuff before entering rolls, 20 to 60 millimetres; size of stuff after leaving rolls, 0 to 6 millimetres; weight crushed per hour, 2½ tons; quantity of stuff crushed by a pair of rolls, 2,000 tons; time required to take off and to put on new rolls, 10 hours; number of hands required at the crusher, 3;

cost of rolls, £18 3s.; labour changing rolls, including cost of iron wedges, &c., £1 7s. 6d.; together, £19 10s. 6d.

	£	s.	d.
Redemption of rolls, less allowance for old rolls	0	0	1¼
Labour cost	0	0	2¼
Steam-power (five horses)	0	0	5
Wear and tear of machinery, oil, &c.	0	0	1
Cost of crushing per ton of stuff	0	0	9½

Fig. 196 illustrates an ordinary Cornish crushing-mill in front and side elevation. The front elevation, Fig. 195, shows the spur gearing driving the rolls, the raff-wheel for lifting to the rolls the stuff crushed but too coarse

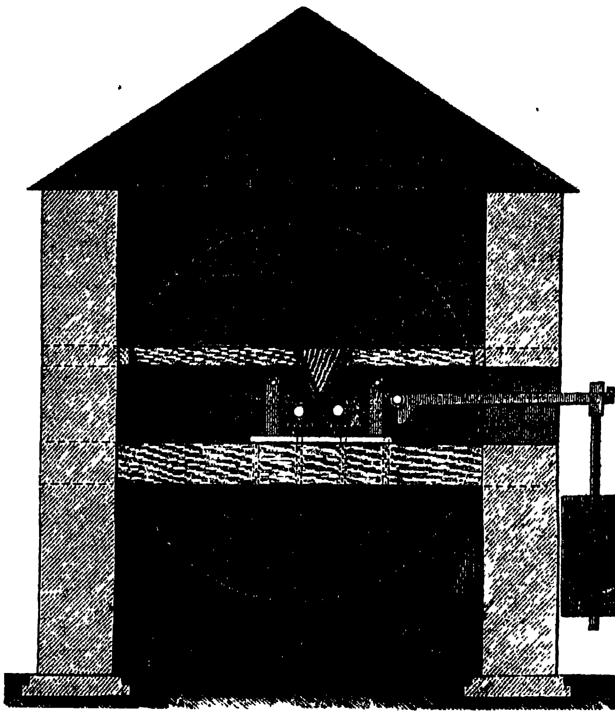

Fig. 196.

to pass through the meshes of the riddle, the inclined shoot for running the stuff to the rolls to be re-crushed, the hopper for supplying the rolls, and a shoot immediately under the rolls for delivering the crushed stuff to an inclined riddle; while the side elevation, Fig. 196, show the ends of the two rolls, the pressing pin and weight lever for keeping the rolls together, and the circumferential line of the raff-wheel. The riddle under the rolls is not shown, but this part of the apparatus divides the crushed stuff into two sizes, viz.:—

Coarse or Roughs.—Returned to rolls by raff-wheel to be re-crushed.

Fine.—Sized and classified for jigging-machine and buddles.

The results of an experiment made for the purpose of determining the sizes into which vein stuff was reduced by means of a pair of rolls is set out in the following table. It will be observed that the proportions of stuff

from $7\frac{1}{2}$ mm. to X to be re-crushed did not exceed 13 per cent., while the proportion of stuff for the classifier varied from 30 to $48\frac{1}{2}$ per cent.

TABLE SHOWING SIZING RESULTS OF SAMPLES OF VEIN STUFF FROM CRUSHING MILL—(1) PROPORTIONS OF STUFF RETURNABLE TO CRUSHING ROLLS; (2) SENT TO JIGGERS; (3) TO BUDDLES OR TABLES.

—	Blende associated with Carbonate of Lime, Quartz, and Galena.		Galena with Carbonate of Lime and Quartz.	Disposition of Stuff.
(1) *For Raff-wheel to Rolls*—	No. 1.	No. 2.	No. 3.	
Stuff from X mm. to 10 mm.	1·45	0·23	3·23	To Crushing Rolls.
" " $7\frac{1}{2}$ mm. to 10 mm.	9·93	3·05	9·46	
(2) *For Trommels*—				
Stuff from 5 mm. to $7\frac{1}{2}$ mm.	12·20	7·91	11·95	To Jigger No. 1.
" " $3\frac{1}{2}$ mm. to 5 mm.	15·35	10·09	17·76	Do. No. 2.
" " 2 mm. to $3\frac{1}{2}$ mm.	12·90	12·16	10·59	Do. No. 3.
" " 1 mm. to 2 mm.	13·83	18·04	16·67	Do. No. 4.
(3) *For Classifier*—				
Stuff from 1 mm. to O	34·34	48·52	30·34	To Buddles.
	100·	100·	100·	

The following table affords particulars connected with the dimension and speed of mills, results obtainable, and horse-power required:—

	Diameter of Rolls in Inches.	Length of Rolls in Inches.	No. of Revolutions of Rolls per Minute.	Speed on Face of Rolls per Minute in Feet.	Quantity of Mineral reduced per Hour.	Horse-power required.
Metalliferous Ores	36	10	10 to 20	90 to 180	5 tons	5 to 8
	27	10	12 " 20	80 " 140	4	4 " 5
Mineral	21	10	15 " 20	80 " 110	3	3 " 4
	15	10	25 " 30	80 " 110	2	$2\frac{1}{2}$ " $3\frac{1}{2}$
	12	10	30	90	$1\frac{1}{2}$	2 " 3
	10	10	40	100		1 " $2\frac{1}{2}$
			(Hand Crushers.)			
	10	10	6 to 9	15 to 20		3 to 4 men
	6	10	50	—		2 " 3 "
	36	30	20 " 30	180 " 270	25	4 to 6
	36	20	20 " 30	180 " 270	15	$3\frac{1}{2}$ " 5
	27	30	25 " 35	170 " 240	25	4 " 6
	27	20	25 " 35	170 " 240	15	3 " 4
	21	30	30 " 40	160 " 270	20	3 " 4
	21	20	30 " 40	100 " 210	10	2 " 3

Stamping Machinery.—The stamping-mill is one of the oldest pulverising machines known in connection with mining and metallurgic operations. In its ordinary form it consists of a number of pestles, arranged so as to be lifted mechanically, each pestle dropping into a coffer, the latter being so comtrived as to admit of a continuous feed and discharge of the stuff. In Agricola's "De re Metallica" illustrations are given (1) of stamps driven by water-wheels with heads beating on a plain bottom; (2) heads falling in a coffer-box, the water and stuff entering at one end and flowing away at the other; (3) coffer-boxes set in front of each other, each fitted with an end grate, the discharge of stuff being into one common launder; and (4) other coffers, with front grates delivering sand to distributors, tables, and riffle-

buddles. In the various examples referred to the batteries are formed of three, four, and five heads. In Pryce's "Mineralogia Cornubiensis," A.D. 1778, a stamping-mill is illustrated, and a description given, from which the following is taken:—

"Seeing that a dresser's judgment is required in the choice of a grate, I begin with the description of that first and necessary part of a stamping-mill which is a thin plate of iron $\frac{1}{16}$ inch thick, 12 inches long, and 10 inches wide. The middle of this, from 8½ inches by 7 inches, is punched full of holes, from the diameter of a small pin to that of a large reed; for the larger the tin crystals inclosing the metal are so much the more capacious must be the holes, and *vice versá*. This holed plate, commonly named the grate, is nailed on the inside of the frame, near the bottom where the stamp-heads pound the ore. . . . . The lifters are three to each stamp, made of ash timber, 6 inches by 7 inches square, and about 9 feet or 10 feet long. They are armed at the bottom with large masses of iron, called stamp-heads, of 140 lbs. weight each or more; these are lifted up and let fall between two upright parallel planks of oak timber by wooden knobs or teeth, called caps, fixed in the barrel of the axletree at proper distances, and in number proportioned to the circumference of the axis, which goes round by the power of the water-wheel. Those caps in their round take up pieces of wood called tongues, about 6 inches projecting from each lifter, which are fixed one in every lifter at a proper place, so that each cap from the barrel of the axle comes under the tongues and lifts them up one after another in a uniform rotation. Each lifter, with its iron head falling upon the tin stuff, bruises it down so small that it is all discharged through the little holes of the grate. The hinder head lifts first, that falling forces the tin stuff under the second, the second falling forces it to the third, that falling forces it on to the small holes in the grate."

Before the end of the sixteenth century stamps were largely employed in the mines of Germany, while from Carew it appears that they were used in Cornwall, for the reduction of tinstone, in the time of Queen Elizabeth. This writer describes the mill as made of "three and in some places sixe great logges of timber bounde at the ends with iron, and lifted up and downe by a wheele driven with water." In 1812 Woolf erected the first steam stamping-mill at Wheal Vor, Cornwall, when the ratchet-wheel became a necessary part of the driving axle. Subsequently at Lanescot, about 1830, wrought-iron lifters and cast-iron angular guides were substituted for "ash timber lifters and guides." In California, since 1850, cast-iron coffers have been used along with movable anvils, dies, gib-tappets, steel cams, and revolving heads; while in Australia the coffers are made of cast-iron or of wood, the latter sometimes encased in iron, each kind of coffer being fitted with a movable cast-iron bed. In Colorado a similar bed is in use, but in Cornwall the bed is generally formed of capel or elvan and quartz beaten into a working condition. In Germany a stone or concrete bottom is frequently made by ramming into the coffer successive layers of quartz and stone; in other cases a cast-iron plate is firmly wedged at the bottom of the box, the interstices being closed by strips of wood. In some cases in Cornwall "flashers" are substituted for grates. In Germany, Rittinger's "Stausatz"

and the Hungarian "Schubersatz" are both employed. In the absence of water for driving stamping-mills steam power is usually resorted to.

The steam-engine invariably employed in Cornwall for driving the Cornish stamps consists of a vertical cylinder, main beam, sweep-rod, heavy fly-wheels, plug valve gear, double-beat valves, condenser, and air-pump. The steam is admitted above and below the piston, and cut off by an expansion slide on the plug rod at any desired point of the stroke. This kind of engine is designated by the Cornish engineer "double-acting," in contradistinction to the "single-acting" character of the Cornish pumping-engine, which admits steam on one side of the piston only. The double-acting stamping-engine also drives the cam-axle direct without the intervention of intermediate gearing, the speed of the stamp-heads or number of drops per minute being obtained by means of cams set in the axle, usually a five-fold multiple of the stroke of the engine itself.

The friction, or loss of power in lifting the heads in a 36-inch cylinder stamping-engine at Wheal Vor, was tested by Mr. Husband, of Hayle, who remarked as follows: "The engine was in good working order, stroke in cylinder 10 feet double acting, and driving 48 heads. We found the indicated horse-power 50, and the actual work done, *i.e.* weight lifted, equal 30 horse-power. The axles, &c., were of the ordinary kind, with five cams in the round, and average lift of heads 6 inches." The loss in running the engine and stamping apparatus was, therefore, 20 horse-power, or 40 per cent. of the indicated horse-power. This loss of power would appear to be unusually great, but it is scarcely to be attributed to the engine or arrangement of stamps; it must rather be ascribed to bad maintenance of the axles, cams, tongues, and lifters.

The duty or useful effect of a steam-engine is the number of pounds lifted 1 foot high by the consumption of a given weight of coal. As an example, 50 heads of stamps may be taken without reference to friction or nature of accessory parts. Weight of head, 584 lbs., less the wear, to average the weight of heads, say, one-third, or net 390 lbs.; lifter and tongue, 275 lbs. = 665 lbs.; number of blows per minute, 50; lift per head, 10 inches. Then $50 \times 665 \times 50 \times \frac{10}{12} = 1{,}385{,}41\dot{6}$ lbs. raised 1 foot per minute. Consumption of coal, 3,920 lbs. in 24 hours, or 100 lbs. of coal in $36 \cdot \frac{7}{10}$ minutes. 1,385,416 lbs. $\times$ 36·7 minutes, give a duty for the consumption of 100 lbs. of coal of 50,844,767 lbs. The horse-power required to lift the foot-pounds per minute is found thus: $\frac{1{,}385{,}416}{33{,}000} = 41 \cdot 9$. Without knowing the construction of the apparatus and incidental work it may have to perform, it is evident that the duty cannot be strictly determined. It is also obvious that the result can only be approximately correct, since the total weight of heads and amount of friction will continually vary.

The number of heads in a coffer is in Cornwall four, occasionally six, as at Wheal Uny; in Germany, three or four; and in America, from three to six, but commonly five. The weight of lifter and head in Cornwall for tinstone varies from 400 to 800 lbs., and in Germany for lead ore from 300 to 500 lbs. In Australia, for reducing quartz, from 300 to 800 lbs., while in America it is

from 600 to 900 lbs. The lift of the head in Cornwall ranges from 8 inches to 10 inches, generally 9 inches; in Germany, for lead ore, from 4 inches to 12 inches; in Australia, for gold quartz, from 5 to 12 inches; and in America, for gold and silver ore, from 4 to 10 inches. The number of drops of the head per minute differs rather with the locality than with the nature of the mineral to be reduced. In Cornwall the number is from 50 to 70; in Germany, with a low fall for skimpings, it is as high as 120; in Australia, from 40 to 80; in California and Nevada, from 70 to 90. Occasionally in the quartz mills of America 120 drops per minute are made, but the fall in such cases rarely exceeds 5 or 6 inches.

The volume of water per head varies with the character of the stuff stamped and the degree of fineness to which it is reduced. For Cornish tinstone the water used is approximately 3 gallons per head per minute; in Australia, from 3½ to 10 gallons per head per minute; while in Nevada it ranges from 1,500 to 1,900 gallons per ton of quartz. In Germany it is reckoned at from 3 to 5 gallons per head per minute. The consumption of fuel is also more or less dependent on the quality of the coal, character and condition of engine, and degree of fineness to which the stuff is to be reduced. In Cornwall from ¾ to 1 cwt. of coal is sufficient to reduce a ton of veinstone to sizes of ½ millimetre and downwards.

The cost of stamping is an item which must necessarily depend upon cost of fuel, labour, and a variety of circumstances connected with the reduction of the stone; but in Cornwall it is accomplished at from 1s. 10d. to 2s., and in Victoria, Australia, from 2s. to 4s. per ton. The fineness to which stone or quartz should be pulverised must depend on the disposition of the ore or fineness of the precious metal associated with its matrix. If either of these should consist of highly minute quantities, the stone must be reduced proportionably fine; if, however, the ore or gold should be somewhat coarsely aggregated with the matrix, then the degree of fineness to which the stone should be reduced may be proportionately lessened. The grates or screens used in stamping-mills are supposed to suit the character of the ore. In Cornwall the grate-hole for tinstone varies from 1 to 1½ millimetre in diameter. The grates are known by consecutive numbers 27 to 39. In America the quartz is passed through fine holes, the size of which is regulated by the sewing-machine needles numbered from zero to 10; No. 8 is $\frac{1}{64}$ and No. 5 about $\frac{1}{16}$ inch diameter. In Australia for the reduction of gold quartz the number of holes per square inch in the screen varies from 60 to 250.

The weight of quartz reduced in a given time is, more or less, consequent on hardness of rock, weight of head, height of fall, rapidity of blows, and number of grate. In California and Nevada the weight reduced is reckoned at 2 tons per 24 hours, in Australia from 1 to 4 tons, and in Cornwall from ¾ to 1 ton. In America the mills are mostly automatically fed, notably by Hendy's feeder, while in Australia feed shoots as well as passes are employed. In Cornwall passes inclined at a suitable angle are invariably used.

The order in which the heads lift and drop in a coffer depends entirely upon the manner in which the engineer has set out the relative position of the cams on the axle. In Cornwall, with four heads in a coffer, it runs 1, 4, 1, 2, and 2, 1, 4, 3; in America, with five heads, the order is 5, 3, 1, 4, 2—1, 3, 5,

2, 4—3, 4, 2, 1, 5—2, 4, 5, 3, 1, or 3, 5, 1, 4, 2; in India the stamps are set to lift and drop in the order of 1, 4, 2, 5, 3; while in Australia, the coffer usually containing five heads, the order of rise and fall is sometimes 3, 5, 1, 4, 2.

Advantages afforded by Stamping Mill.—The following are among some of the advantages afforded by the stamping-mill:—(1.) It gives a dead blow, highly effective in reducing semi-elastic minerals. (2.) The force of the blow can be readily modified by shifting the position of the tappet. (3.) The free fall of the head is entirely exerted on the stuff, and its effect is in no way transferred to the framework or other parts of the apparatus. (4.) The repairs required are few and simple, such as an ordinary mine smith and carpenter can execute. (5.) A single battery of heads may be stopped and repaired while others are running. (6.) Single heads may be thrown out of use without affecting the working conditions of the mill. (7.) The mineral under treatment receives the least possible handling, and can be flumed at once either to dressing or amalgamating apparatus. (8.) Minerals can be readily reduced to a condition of fine sand provided the faces of the heads are good. (9.) Speed, lift, weight, size, form of head, position of discharge, and extent of grateway admit of numerous variations to suit the conditions of different minerals, and afford a wide field for the exercise of intelligence, judgment, and practical skill.

The power, and water, required for running a mill must necessarily be of a variable character. In the Western States of America the object of the miner and millman is to reduce the largest possible weight of quartz per head, per day of 24 hours, and the whole tendency of their practice is to increase the weight of the head, lessen the length of its drop, and augment the number of drops per minute. The head and its accessories now weigh from 750 to 900 lbs. In a 40-head stamp-mill, reducing 100 tons of quartz per day of 24 hours, the following approximate figures apply:—

	Horse-power.
(1) *Power*—1 Stone-breaker, shaft making 175 revolutions per minute	5·0
8 Automatic feeders	2·0
40 Heads 750 lbs. each, making 90·8 inch drops per minute	54·5
10 Grinding and amalgamating pans, each 65 revolutions per minute	72·0
8 Separators, each 8 revolutions per minute	16·6
1 Agitator, making 50 revolutions per minute	3·0
4 Concentrators, each making 200 revolutions per minute	8·0
Friction, one-third or 33 per cent.	53·5
Total Horse-power	214·0

	Water required per Minute. Pounds.		Gallons.
(2) *Water*—214 Horse-power	170	or	17
40 Heads	625	„	62½
16 Grinding and amalgamating pans	375	„	37½
8 Separators	115	„	11½
Total water required	1285		128½

Or say,

For boiler	7½	gallons per horse-power per hour
„ each stamp head	72	„ per hour.
„ „ 5-feet pan	120	„ „
„ „ 8-feet settler	60	„ „

For the milling of gold and silver ores, the usual rate of the weight of water to that of rock is as nine to two (9 : 2):—

	Water per Ton of Ore.		
	Cubic feet.	Gallons.	Pounds.
Stamping	144	900	9,000
Grinding and amalgamating	86·4	540	5,400
Separating or settling	25·9	161·7	1,617
Silver mill, including horse-power.	293·2	1832·5	18,325

In working the copper ores of Lake Superior, 20 cubic feet or 125 gallons of water to 1 cubic foot of ore are used, or equivalent to 8 to 1 by weight.

In many mines in America valuable quantities of brittle sulphide of silver are mechanically associated with the ores. At Butte, Montana, the ores include the sulphides of silver, antimony, lead, and zinc, together with a little copper ore and manganese.

The ores are stamped *dry* without the admission of water to the coffer, hence the volume of water required for *dry* is much less than that necessary for wet stamping. A ten-head dry stamping-mill will use—

For steam and general purposes, per minute . .	4 gallons .	40 lbs.
Four grinding and amalgamating pans, per minute .	6½ ,, .	65 ,,
Two settlers, per minute	2 .. .	20 ..
	12½ ,, or	125 ,,

The water used for stamps, pans, and settlers, after a loss of about 30 per cent. of its weight, can be pumped and re-used in the machinery.

TYPES OF STAMPING APPARATUS.

Class of Stamps.	Pulverising Character.	Type.
(A.) Gravitation stamps . .	Pulverization effected by the weight of head falling through a given height.	Cornish stamps. Californian ,, Australian ,,
(B.) Direct-acting steam stamps	Pulverization effected by the weight of head plussed by the expansive force of the steam employed.	Wilson's stamps. Ball's stamp.
(C.) Crank and spring stamps	Pulverization effected by means of a crank and spring, the blow being intensified by the excess of movement which may prevail over and above that consequent on weight and force of gravitation.	Husband's pneumatic stamps. Scholl's ditto. Patterson's mechanical spring ditto.

(A.) *Cornish Gravitation Stamps.*—In Cornwall the weight of tinstone stamped per annum is estimated at 600,000 tons; requiring about 2,000 horse-power, or 300 tons of tinstone per horse-power per annum. The average weight of a head without lifter is 4½ cwts., with lifter 6 to 7 cwts. The average life of a head is about 4 months, while the loss of chilled cast iron in stamping a ton of stuff is about 3lbs. The weight of tinstone stamped per 24 hours varies from 15 to 20 cwts., which is more or less increased, by first preparing the stone by means of a stone-breaker, to the extent of from 15 to 20 per cent., which will give respectively about 17 and 24 cwts. per 24 hours. The

lifters are usually made of flat wrought iron about 3½ inches wide by 2 inches thick, and the head of hard chilled cast iron about 22 inches long by 11 inches wide and 7 inches thick. The average lift is about 9 inches, the maximum 10, and minimum lift 7 inches. The tongues on the lifters are made of wrought iron steeled, and the cams on the axle of cast iron. The coffers are generally made of wood, the grate-plates being of copper with a variable number of holes per square inch. The size of the holes is of considerable importance, and is determined according to the quality and degree of fineness of the grains of oxide of tin in the stuff to be stamped. The stamps are arranged in long rows, each axle lifting 16 heads, set in 4 coffers. In some mines there are as many as 25 sets of coffers or 100 heads. One of the drawbacks alleged to be consequent on slow stamping (50 to 70 drops per minute) is the production of an unusual proportion of slime containing minute grains of oxide of tin not directly obtainable by the ordinary method of dressing. At West Wheal Peevor the grates employed are known as No. 36, answering to No. 6 American needle. The holes on the inside or end of the "punched burr" are about $\frac{1}{50}$th of an inch in diameter. A sample of stuff stamped and passed through the grate was sized, and afforded the following results :—

From $\frac{1}{50}$th of an inch diameter to grains passing through wove wire work, 6,000 holes per square inch . . .	26·7 per cent.
„ 6,000 to 12,000 holes per square inch	13·2 „
„ 12,000 to the fineness of zero per square inch . . .	60·1 „

It will thus appear that the greater portion of the stuff reduced was, in its grain size, very much finer than the diameter of the hole in the grate through which it passed. In this case, admixed with water, the fine slime may be reckoned at 13·2 per cent., and the impalpable slime at 60·1 per cent. The tinstone (tin stuff) is usually brought to the stamps, Fig. 199, in tram waggons and tipped upon an inclined plane, known as the pass and half-pass. The inclination of the pass is about 1 in 1½ foot, and that of the half-pass 1 in 2¼ feet. The half-pass leading down to the coffer mainly regulates the speed at which the heads are fed. The exact amount, however, is, as it were, obtained by the continuous flow of a small stream of water upon the stuff itself. This water goes into the coffer along with the stuff when the stamps reduces the latter to a fine powder and "flashes" it through the grates set in the front and ends of the coffer.

In a communication made by the late Mr. John Hocking, to the Mining Institute of Cornwall, on the subject of a new 40-inch cylinder stamping-engine erected at West Basset, he observed: "When the erection of the new engine was determined on, we resolved that everything that was possible should be done to economise fuel and to reduce the cost of dressing to a minimum point. To economise fuel and to produce the best stamping results three things were essential: (1.) The construction of an engine and buildings of sufficient strength to allow of a high rate of expansion of steam. (2.) Boilers of the best and most approved construction and strength to work high-pressure steam, and of sufficient power and heating surfaces without forcing the fires. (3.) Stamp heads and lifters of unusual weight, and for the

dressing department a site by which the different dressing processes follow each other by their own gravitation, and thus to avoid the cost of lifting the ore back by hand labour and by artificial means." The main particulars connected with the West Basset engine and stamps may be abbreviated as follows: Stroke of engine 9 feet, double acting; number of heads attached to engine, 4 axles of 16 heads each, or total 64; average number of revolutions per minute, including stoppages, 10·7; load per square inch on piston, 9·31 lbs.; consumption of coals per week, 17 tons; duty of engine, $66\frac{3}{10}$ths million of pounds lifted 1 foot high; quantity of tinstone stamped, 621 tons; coal consumed for stamping one ton of tinstone, $61\frac{3}{10}$ths lbs.; weight of tinstone stamped per head per day after allowing for stoppages, $34\frac{3}{4}$ cwts.; average weight of head and lifter, 877 lbs. Total load in foot pounds, 210,480. The steam to the cylinder was admitted at a pressure of about 18 lbs. per square inch and cut off at a little less than $\frac{1}{10}$th of the stroke; the boilers were fitted with cone tubes, while the stamp lifters were of increased size and length, viz. $3\frac{1}{2}$ inches wide, $2\frac{1}{2}$ inches thick, and 16 feet long. The cost of keeping the stamps in repair, allowing for wear and tear, exclusive of grate-plates and smith cost, was (1877) $3\frac{1}{4}$d. to $3\frac{1}{2}$d. per ton of tinstone stamped. The quantity of water required for dressing purposes for 80 heads, reducing 70 tons of tinstone per 24 hours, was 800 gallons per minute, or roundly 400 gallons of water for every pound of black tin rendered fit for the smelting furnace. The direct cost of stamping was—wear and tear of machinery and apparatus, $3\frac{1}{2}$d. per ton; coal, $61\frac{3}{10}$ lbs.; at 17s. per ton, $5\frac{1}{2}$d.; or together 9d. per ton. The various cost per ton of tinstone may be thus specifically stated :—

Keeping stamps in repair	$3\frac{1}{2}$d. per ton.
Direct cost of stamping, exclusive of interest on plant .	$5\frac{1}{2}$d. „
	9d.
Interest at 5 per cent. on cost of plant, reckoned at £4,000, and life of plant at 14 years	$2\frac{1}{2}$d.
Total	$11\frac{1}{2}$d.

The following are some results connected with steam stamps formerly in use at Polberro, St. Agnes, and Wheal Polrose, Breage, Cornwall.

Polberro.—Diameter of engine cylinder, 36 inches; actual horse-power employed in stamping stuff, 55; number of tons of tinstone stamped during 1856, 31,411. This result was accomplished at the rate of $8\frac{1}{2}$ strokes per minute in the engine, with an equal number of revolutions in the cam shaft, lifting 72 heads 9 inches high, each head weighing respectively 600 lbs. The maximum number of blows made per minute was 50, the average number 45. Two fly-wheels attached to the engine, each 30 feet diameter, weighed $34\frac{1}{2}$ tons, and with crank shaft and bolts the weight of metal was $42\frac{1}{2}$ tons. The total cost of stamping, including maintenance of engine, wear and tear of machinery, wages of all kind, coal, oil, grease, hemp, &c., divided by the tons stamped, amounted to 1s. $3\frac{1}{2}$d. per ton.

Each head stamped 436 tons per annum, or 28 cwts. per 24 hours, while the whole number reduced 100 tons daily at a cost of 2s. 4d. per horse-power. The stamp heads and accessories weighed collectively $19\frac{1}{4}$ tons, and as the drop was 9 inches per head and 45 drops were made per minute, it follows

that a mass equal to 877 tons was lifted through a height of $33\frac{1}{2}$ feet in a corresponding period. The screens were 72 in number. The dimensions of

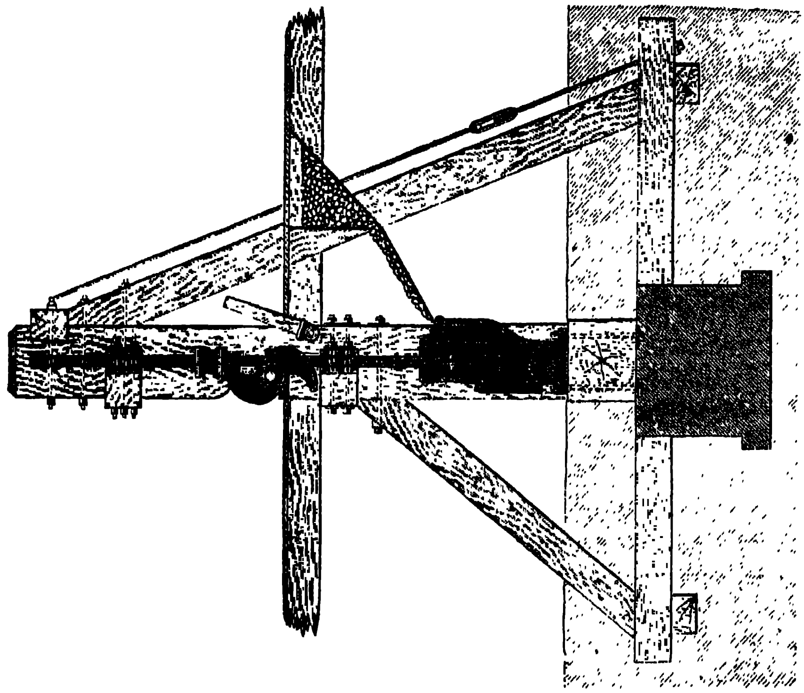

Fig. 198.

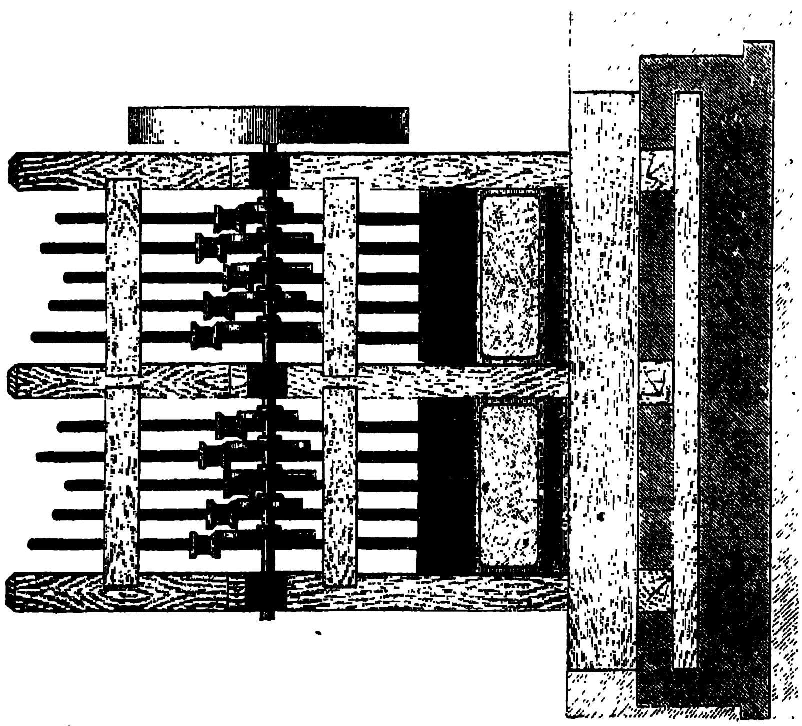

Fig. 197.

grates to each coffer were—front screen 9 by 6 inches, two end screens, each 8 by 6 inches, number of holes in screen 140 per square inch (Figs. 197, 198).

Whcal Polrose.—The diameter of the steam cylinder was 30 inches; length of stroke, 7 feet; number of heads attached to engine, 60; weight of each head and lifter, 7 cwts. The stuff was partly stamped through flashers and partly through screens, the latter were 11 inches by 9 inches, punched with holes ⅛ mm. diameter; the number of blows per minute per head was, 55; and weight of stuff stamped per head per 24 hours, 25 to 28 cwts.

Californian and Australian Stamps.—The Californian and Australian stamps differ in many respects from the Cornish stamps: (1) the heads and lifters are round; (2) the tappets are lifted by means of cams developed to the form of an involute curve; (3) the heads partially rotate during the lifting operation; (4) the coffers are of cast iron with heavy cast-iron bottom; (5) movable shoes are attached to the heads; (6) movable dies are placed at the bottom of the coffer; (7) grates are not placed in the ends of the coffer; (8) the speed or number of drops per minute varies from 70 to 120; (9) the foundations for the coffers are formed of heavy blocks of timber; (10) five heads are invariably placed in a coffer. Figs. 197 and 198 illustrate stamps made by an eminent Cornish firm in which most of the special details of a Californian stamps are introduced.

The illustrations (Figs. 199 and 200) represent front and end elevation of eight heads of Cornish stamps supposed to be driven by a water-wheel and spur gear. The stuff is first lodged in the pass or hopper, from whence it gravitates to the half-pass into the coffer, where it is stamped. Each coffer is provided with two front and two end grates, and contains four heads. The axle in front of the lifters is fitted with three tappets "on the round," each single head lifting three times during a revolution. The shanks and lifters are made of best selected scrap iron, and the heads, from 3 to 6 cwts. each, are cast in chills from a special mixture of hard, white iron. The lift of the head is about 9 inches, and at 70 drops per minute the stamping capacity may be reckoned to be 20 to 25 cwts. per head per 24 hours.

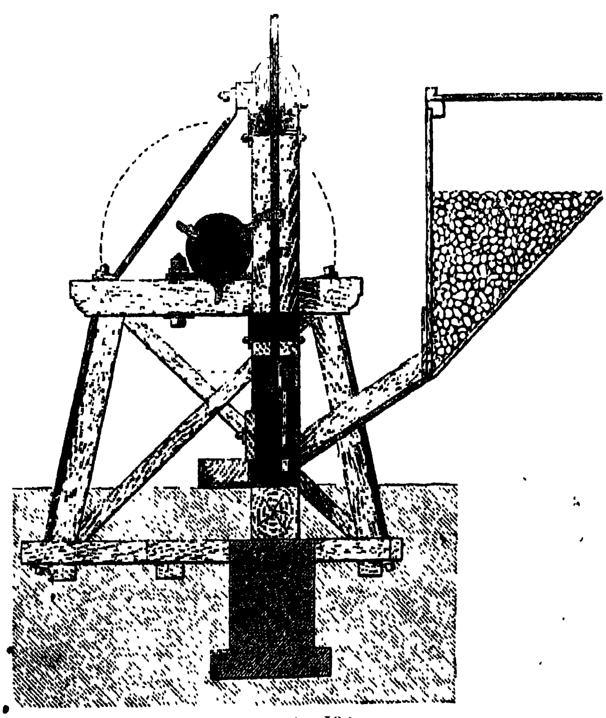

Fig. 199.

The illustrations show the woodwork, bed, log, and wall, or concrete foundation.

(B.) *Direct Acting Steam Stamps.*—Various attempts have been made to

apply steam direct to the lifting of stamp-heads. Wilson of Philadelphia, Pennsylvania, contrived a battery consisting of two direct-acting steam cylinders, and valves worked with tappets set on the stamp-lifters. The steam pressure, applied to cylinders $5\frac{5}{8}$ inches diameter and $7\frac{1}{2}$ inches long, was 65 lbs. per square inch. Ball of Lake Superior has also successfully contrived a direct-acting steam stamps for the reduction of amygdaloid and conglomerate containing native copper. In the largest machine yet constructed the weight of head, lifter, and shoe is about 2 tons, extreme length of stroke 28 inches, number of drops per minute 90, horse-power required 60, weight of stuff reduced and passed per 24 hours, through grates with holes $\frac{1}{16}$ inch diameter, 110 tons. The movement of the piston is effected by a valve worked by an independent motor, one man being employed to look after the valves to two machines. To prevent the striking of the cylinder covers stops are employed. At the Atlantic mill the steam goes into the stamps cylinders at a pressure of 65 lbs. per square inch, the exhaust steam runs into a receiver and heater 50 feet long and 2 feet in diameter, the steam pipe from which goes to the main mill. The weight of coal consumed to a ton of stamped rock is about 100 lbs. About 25 tons of water are required to a ton of rock. A bed of stuff always lies on the coffer, which prevents the head from coming in contact with the die. The "waste" of the head is said to be one pound of cast iron to four tons of stamped stuff.

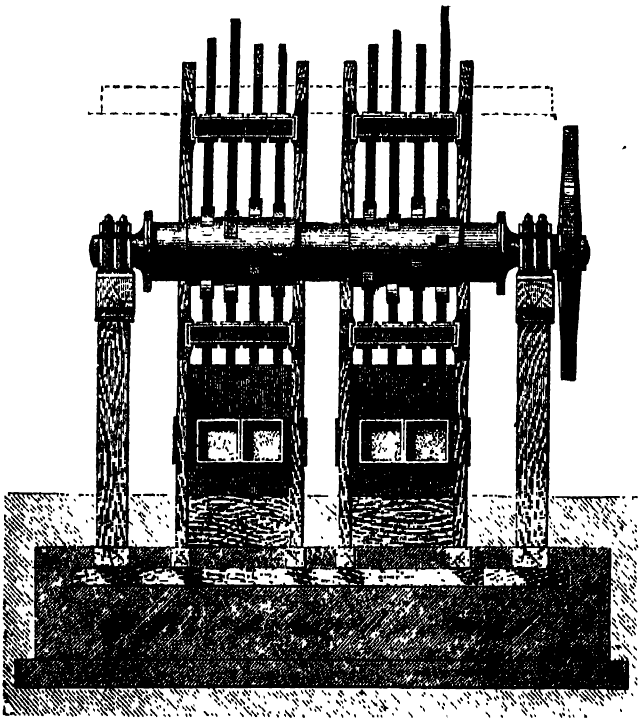

Fig. 200.

(C.) *Crank and Spring Stamps.*—Fig. 201 represents Husband's pneumatic stamps.

The stamp-head is not lifted direct, but is attached to a piston working in an air-cylinder, and this cylinder has a reciprocating motion imparted to it by a crank-shaft through a forked connecting-rod coupled to trunnions upon the cylinder. When the cylinder is raised by the crank, the air *below* the piston is compressed and the stamp is thrown up; and on the crank turning the centre, the air *above* the piston is compressed and the stamp is driven down with a velocity considerably greater than that due to its weight and natural fall. The stamp-head and piston-rod, weighing together nearly 3 cwts., fall about 16 inches, with a stroke of 10 inches in the crank, and make

from 120 to 150 blows per minute. A ring of small holes is made around each cylinder immediately above and below the central position of the piston, so that both ends of the cylinder may be filled at each stroke with air. A continuous stream of water flows through the hollow piston-rod, for the purpose of neutralising the heat developed by the rapid compression of the air *trapped within* the cylinder. This water is discharged through small holes at the bottom of the piston-rod, just above the stamp-head, and serves as part of the supply of water for the stamping operation. A considerable portion of the water necessary for the stamp-head is delivered in a circular jet under several feet of head to the outside of the piston-rods passing through the coffer cover. In order to prevent the unequal wear of the stamp-heads, which would arise from the supply of fresh uncrushed stone to one side only, horns are employed for turning the heads. About once a day the position of the heads is shifted, so as to cause the stamp-head to wear in a fresh place. These pneumatic stamps, hitherto mostly erected in pairs, are said to reduce from 8 to 10 tons of tinstone per head per day.

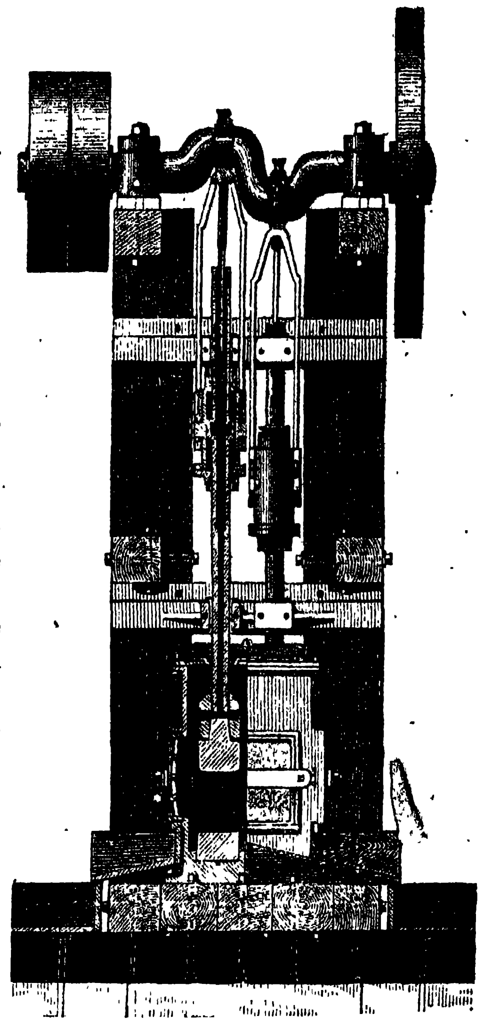

Fig. 201.

In some stamps erected the total weight of head and lifter was from 310 to 320, and it required about 12 indicated horse-power to drive a pair of such heads at 150 blows per minute. The weight of coal required to stamp the tin stuff at Carn Galver mine, where two heads were driven by a combined engine, with 9 and 17 inches cylinder, 15 inches stroke, and 70 lbs. of steam per square inch on piston, was about 1 cwt. to 1¼ ton of tinstone. At New Rosewarne mine, Gwinnear, 196 tons of tin stuff were stamped with a consumption of 156 cwts. of coal; or about 1¼ ton stamped per cwt. of coal. Less slime was produced in these than in the ordinary stamps, from the circumstance that the contents in the coffer were kept in a continuous state of agitation, driven quickly against the grates, and forced through the holes as soon as it had come to the required size. The "wear" or loss of iron in the stamp-heads was about 1 ton to 1,000 tons of reduced tinstone. This result was partly attributed to the periodical turning and regular wear of the heads, and to casting the head with a hole up the centre.

The cost of a set of stamps equal to 70 heads of ordinary Cornish stamps, including a driving-engine, but excluding cost of boiler, is about £1,400. Less water for stamping a given weight of stuff is required than in the Cornish stamps.

At Tregembo mine, St. Hilary, Cornwall, two single-head oscillating stamps are in use. The weight of each head is 9 cwts., horse-power required per head 16, number of tons of tinstone stamped per day of 24 hours through grate-holes 1 mm. diameter, or No. 32 Cornish gauge, 13 to 15 per head, fall of head 14 to 15 inches, number of blows per minute 120. The loss of iron per head to stamp a ton of stuff varies from $1\frac{3}{4}$ to $2\frac{1}{2}$ lbs. The total area of the grates, which consist of punched copper-plates, is 10 square feet.

A sample of stuff, taken after it had passed through the grate-holes 1 mm. diameter, was sized through three sieves with the following results:—

Size of grains which passed through grate-holes 1 mm. diameter, but would not pass through a wire sieve 6,000 holes per square inch	54·0 per cent.
Size of grains which passed through sieve 6,000 holes, but would not pass through sieve 12,000 holes per square inch	10·8 „
Size of grains which passed through sieve 12,000 holes per square inch, and which would form in water a gritless slime	35·2 „

With these stamps the quick and lively blow keeps the water in agitation, and the large grates allow the stamped stuff to escape quickly. The heads, or shoes, also wear flat and square, and do not present the ragged appearance of ordinary rectangular-shaped heads after they have been much used.

According to Mr. Husband, of Hayle, the relative resistance offered by various kinds of rocks to the pulverising action of the pneumatic stamps, taking the hardness of Clay-Slate to be 1, is as follows:—

Clay-Slate	1·00	Mellanear Mine Lode Stuff	1·60
Broken Fire Brick	1·00	West Seton „	1·60
Ordinary Cornish Brick	1·24	Blue Elvan (Road Metal)	1·80
Granite or Quartz, of average hardness	1·30	Dolcoath Mine Lode Stuff, Hard Capel	2·30
Limestone	1·40		

Mr. Husband also states that the quantity of stone reduced in a given time, within certain limits, with heads varying from 2 to 8 cwts. each, is directly in proportion to the total weight of the head and lifter, each having the same fall and making a like number of blows per minute.

Scholl's Stamps.—The following are a few particulars relating to Scholl's pneumatic stamps, erected at St. Just in 1878. Stamps consisted of two heads and two cylinders. Diameter of steam cylinders 9 inches, stroke 10 inches, pressure of steam employed 50 lbs., cut off at $\frac{3}{4}$ of length of stroke, number of beats of each head per minute 140, lift of head 16 to 17 inches, diameter of head 12 inches.

Patterson's Stamps.—This stamps, known as the "Elephant Stamps," was designed by Mr. Patterson to replace the heavy and more costly gravitation stamps. The novelty of this machine consists in the insertion of a semi-circular bow and volute spring, between the driving-shaft and the lever. It is alleged that the spring, acting as a cushion, takes up the greater part of the wear and tear of the machine, which from the violence of the

blows would otherwise be considerable—an objection applying to other machines of this class striking very severe blows, and running at a high speed.

Power is also economised by the use of springs and steel levers in place of stamp-rods, guides, and cams, friction being thereby greatly reduced. The makers, the Sandycroft Foundry Company, attribute many advantages to the use of these stamps, viz. (1) *portability*, the heaviest piece not exceeding 6 cwts.; (2) *prospecting purposes*—a small battery can be put to work quickly and driven by horses, mules, or bullocks; (3) *saving of fuel*—much less power is required to drive these to accomplish a given result than is necessary to run the ordinary stamps; (4) *elasticity of blow*—the blow struck is the most elastic that can be produced, the sliming of the stuff being thereby reduced to a minimum quantity, while the weight of blow can be varied at will from a light blow to that of the heaviest stamp, to suit the hardness of the stuff to be reduced. The total weight of the machine is about 2½ tons. The mortar-box is made to take three screens, one in front and one at each end, the screen area being 350 square inches, or 175 square inches per head. The speed of the crank should be such as to drive the heads from 180 to 200 blows per minute. The height of blow at such speed will be about 10 inches. From eight to ten gallons of water per minute will be required per pair of heads.

At the Indian Consolidated Gold Mines in the Wynaad, Southern India, where six sets of elephant stamps were erected, it was found that the power required to run three batteries at 140 revolutions per minute was 11 horse-power, from which must be deducted the power absorbed in running the engine, shafting, gearing, and pulleys, amounting to 2·7 horse-power, which left 8·3 horse-power to be divided among three batteries, or 2¾ horse-power per battery. The loss of weight in heads and dies stamping a very hard keen-cutting quartz was 110 lbs. per 150 tons, or barely ¾ lb. of steel per ton of quartz. The quartz was reduced to pass through screens 800 holes to the square inch, and about one ton of damp firewood was sufficient to run a battery at 140 revolutions per minute for a day of 24 hours.

Pulverising.—The difficulty in dealing with slimes with the ordinary dressing appliances, arises from the circumstance that the grains of tin ore are very minute compared with the particles of foreign matter with which they are mixed. They are consequently carried away in suspension by the water in consequence of their extreme absolute lightness, although their specific gravity is greater than that of the larger particles of foreign matter with which they are associated. For the purpose of reducing the particles of foreign matter to the same size as the tin grains, and thereby enabling the latter to be separated by the ordinary dressing-machines, several different "pulverisers" have been introduced, having either a reciprocating or a rotary motion; these have been found very successful in pulverising the waste, or "roughs," previously thrown away, because the cost of reducing the product by restamping was greater than the value of the oxide of tin obtained.

Dingey's Pulveriser is in successful operation at several mines in Cornwall and abroad. It consists of a shallow pan 6 feet internal diameter, having

vertical sides, fitted with a series of grates, through which the pulverised material is delivered. Four annular grinding discs, or runners, 2½ feet diameter, and geared together, revolve upon the bottom of the pan at a speed of 200 revolutions per minute, while the pan itself is made to revolve slowly at four or five revolutions per minute, so as to avoid any tendency to wearing the grinding surfaces into grooves. The wearing surface of the bottom of the pan is a separate cast-iron plate, with a number of holes in it forming shallow recesses, in which the stuff to be pulverised is retained whilst the grinding runners act upon it. The stuff mixed with a stream of water is supplied by a launder into a central annular trough, from which it is delivered by spouts into the centre of each of the grinding runners, and having been ground by passing under the runners, it escapes with the water through the grates in the sides of the pan into an external trough, from whence it is conveyed direct to the buddles. The shoes of the grinding runners, as well as the bottom of the pan, are separate castings 1½ inch thick, so as to be readily replaced when required. The space between the grinding faces of the shoes and the bottom of the pan is adjusted by hand-regulating screws

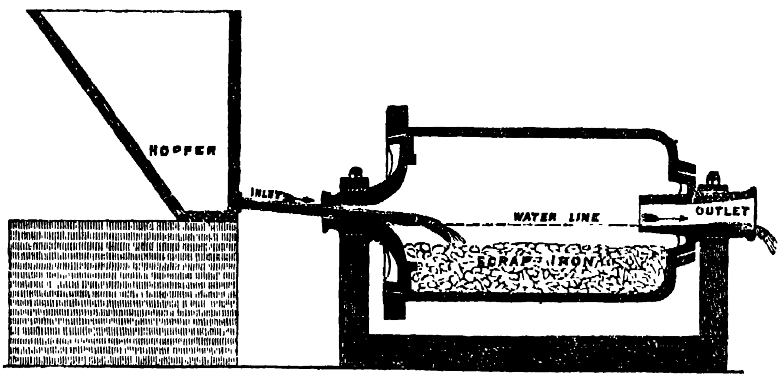

Fig. 202.

and levers supporting the runner spindles. The weight of the whole machine is about 4 tons, and it will grind from 15 to 20 tons per day of 24 hours according to the class of stuff treated.

Michell and Tregoning's Pulveriser, Fig. 202.—This pulveriser consists of a cast or wrought iron cylinder, a charging hopper, inlet charging pipe, an outlet delivery pipe, and a wooden tank. The operation of the machine is exceedingly simple. The cylinder is charged with from 12 to 15 cwts. of small scrap iron, and the sand to be ground is conveyed to the cylinder from the hopper through a pipe by means of a small stream of water, which can be regulated at will. The cylinder then revolves, when the movement of the iron grinds or pulverises the sand. The scrap iron presents from 40,000 to 50,000 square inches of rubbing or grinding surface, and as soon as the stanniferous sand is ground sufficiently fine it is discharged at the outlet end of the cylinder. The degree of fineness to which the sand is pulverised is in proportion to the rate at which it is supplied to the cylinder. A lad 15 years of age attends two machines.

At Wheal Agar, Redruth, a large pulveriser is employed, the inner length

of the cylinder is 5½ feet, diameter 56 inches. The cylinder is fixed in an horizontal position, and when pulverising hard stuff it makes 16 revolutions per minute. For soft stuff the speed is reduced to 14 revolutions per minute. The weight of scrap iron within the cylinder is from 10 to 12 cwts., about 56 lbs. of which is ground up in effecting the pulverization of 30 tons of stuff, or a loss of 1·86 lb. of iron to one ton of stuff. The following are the relative proportions of the various sizes of the stuff before entering and after passing out of the cylinder:—

	Before Pulverization. Per cent.	After Pulverization. Per cent.
Grains which would not pass through a wire-wove sieve 6,000 holes per square inch	22·3	Nil.
Grains which passed through a sieve 6,000 holes, but which would not pass through 12,000 holes per square inch	14·8	,,
Grains which passed through a sieve 12,000 holes per square inch	62·9	100·0
		100·0

The weight of stuff pulverised in 24 hours at a speed of 16 revolutions per minute is from 5 to 6 tons. The quantity of water required to dilute and carry off the pulverised sand is from 10 to 12 gallons per minute.

At Wheal Peevor, the burnt leavings afforded by sizing before and after pulverization:—

	Before Pulverization. Per cent.	After Pulverization. Per cent.
Grains which would not pass through wire-wove sieve 6,000 holes per square inch	17·6	Nil.
Grains which passed through a sieve 6,000 holes, but would not go through a sieve 12,000 holes per square inch	10·5	0·2
Grains which passed through sieve 12,000 holes per square inch	71·9	98·8
	100·0	100·0

The following proportions of grain sizes constituted a sample of roughs from Wheal Uny before and after pulverization:—

	Before Pulverization Per cent.	After Pulverization. Per cent.
Grains which would not pass through sieve 6,000 holes per square inch	63·0	Nil.
Grains which passed through 6,000 holes, but would not go through a sieve 12,000 holes per square inch	18·5	1·7
Grains which passed through sieve 12,000 holes per square inch	18·5	98·3
	100·0	100·0

Cunnack's Pulveriser.—This pulveriser is constructed with a circular bottom, about 3½ feet diameter, surrounded by a shallow pan, a disc 2½ feet diameter, and a vertical crank shaft, for giving the disc an eccentric movement. Renewable grinding-shoes are fitted to the bottom as well as to the movable disc. The weight of the shoe is about 3½ cwts., which, with constant use, requires renewal once every three months. About 1½ horse-power is necessary to run the disc 40 revolutions per minute. The stuff to be pulverised is introduced between the disc and the bottom, and its fineness or coarseness is regulated by increasing or diminishing the quantity of water in the pan. At Wheal Uny, Redruth, the weight of stuff reduced per 24 hours with one machine is about 7 tons. A sample of "burnt leavings"

before and after pulverization was sized through three sieves, when the following results were obtained:—

	Before Pulverization. Per cent.	After Pulverization. Per cent.
Stuff which would not pass through wire-wove sieve 6,000 holes per square inch	15·0	Nil.
Stuff which passed through 6,000 holes, but would not pass through sieve 12,000 holes per square inch . . .	20·8	2·6
Stuff which passed through sieve 12,000 holes per square inch	64·2	97·4
	100·0	100·0

Nicholas's Pulveriser.—This apparatus is in use at Wheal Uny, West Basset, Wheal Agar, and other mines in the Redruth district. It consists of a stationary horizontal cylinder, closed at the ends, 4½ feet long and 2½ feet diameter; a revolving barrel on an axis, within the cylinder, fitted with grinding rubbers, a false bottom set within the cylinder, extending upwards and around for about two-thirds of the inner circumference of the stationary cylinder; an inlet and outlet passage for the stuff, levers and weights at the ends of the cylinder, set under the axis, for adjusting the rubbers, so as to grind the stuff to the required degree of fineness. The grinding barrel makes from 30 to 40 revolutions per minute. At this speed about 1½ horse-power is necessary, and 6 tons of roughs or 8 tons of burnt leavings are pulverised in 24 hours. Four samples of stuff, sized before and after pulverization, gave the following results :—

	Wheal Uny.		West Basset.				Wheal Agar.	
	Burnt Leavings Pulverised.		Burnt Leavings Pulverised.		Roughs Pulverised.		Burnt Leavings Pulverised.	
	Before.	After.	Before.	After.	Before.	After.	Before.	After.
Grains which would not pass through sieve 6,000 holes per square inch.	28·4	2·1	66·0		50·9	1·6	72·9	
Grains which passed through sieve 6,000 holes, but would not pass through sieve 12,000 holes per square inch	17·3	3·3	13·7	0·3	24·1	15·1	15·1	2·9
Grains which passed through sieve 12,000 holes per square inch .	54·3	94·6	20·3	99·7	25·0	83·3	12·0	97·1
	100·0	100·0	100·0	100·0	100·0	100·0	100·0	100·0

Jordan's Pulveriser.—The machine made by Jordan and Son is formed of a chamber and two sets of pulverising arms. The following is a short description of the machine and explanation of its working.

Two circular dished castings, each having a long bearing projecting from its centre, are bolted together by flanges, and form the crushing chamber D D, which has an inlet opening on the top E, and two outlet openings, one on each side. The two bearings carry short wrought-iron spindles which meet end to end in the centre of the crushing chamber. On the inner end of each spindle is keyed a set of four arms, H H H H, the diameter of the chamber, the surfaces of the one set of arms being so angled at 45° with the horizontal centre line that they are parallel to and face those of the other set.

These arms pass in opposite directions close to each other and to the sides of the chamber, and their backs are so formed as to create a blowing or fan action in the chamber, drawing air through openings in the sides and near the centre of the chamber. On the outer end of the spindles are keyed pulleys for driving by belts, the spindles and their arms and pulleys being quite free and independent of each other to turn in reverse direction. One of the spindles has a worm engaging a wheel, and working a vertical shaft; it drives at a given speed the automatic feeder M. By means of driving belts on the pulleys, the spindles and their arms are revolved in reverse directions at any suitable speed for the material to be crushed. The material falling into the chamber from the automatic feeder M is struck by one of the arms (owing to the angle of its face) into the path of those revolving in the reverse direction, and is by them, for the same reason, immediately returned; thus it is with great force struck to and fro from arm to arm. There is, therefore, no grinding action, the crushing being done entirely by percussion or impact, but without centrifugal force. The fineness of the material leaving the machine is regulated by the current of air, which immediately takes away, through A A, all particles light enough for the current to suspend, and the force of this current can be adjusted to the greatest nicety, by simply closing or opening the apertures in the casing for that purpose. The current in the machine is sufficient to carry the crushed material up 10 or 20 feet of pipes to another chamber, the height of the column of pipes regulating also the size of the particles delivered, different sizes being delivered at various levels if required.

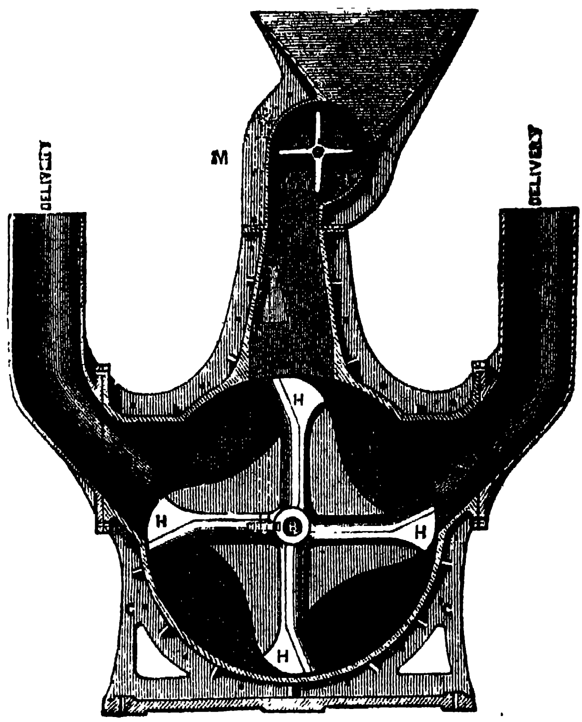

Fig. 203.

Chilian Mill.—This apparatus, for the reduction of silver ores and amalgamating purposes, is employed to a limited extent in Australia. A single runner, 6 feet diameter, 16 inches thick at the edge, running 200 feet per minute, will reduce about 7 cwts. of stuff from grain sizes of 10 to 60 holes per lineal inch per day of 24 hours.

Horizontal Mill.—A mill constructed of flat burr stones, almost similar to a flour-mill, is found to grind certain ores very effectively, although but a limited weight is produced in a given time. A stone 4 feet diameter and 12 inches thick, and a runner 14 inches thick, the latter making 100 revolutions

per minute, will grind 1 ton of stuff from a mesh size of 100 holes to 3,600 holes per square inch in a period of 10 hours.

Carr's Pulveriser.—This apparatus is formed of two disintegrating wheels placed in a close case. On the face of each wheel is a series of projecting pins, which are so arranged as to revolve concentrically with each other. The wheels rapidly revolve in opposite directions, and the stuff falling into the apparatus is projected from one pin to another with great velocity and shattered into dust. Wheels, 6 feet diameter, for the reduction of copper or silver ores, making 500 revolutions per minute, reduce from 5 to 6 tons of stuff per hour, and require 20 horse-power.

Arrastre.—The Arrastre is, perhaps, one of the rudest and most simple of all pulverisers. It includes a vertical spindle of wood, a couple of wooden arms, a closely-laid stone bottom, and a wood or stone ring to form a basin. Two basaltic or other hard stones are used as runners, which are dragged upon the bottom frequently by mules, but sometimes by means of steam-power. A machine in good working condition will grind from 600 to 800 lbs. of ore into very fine slime or mud in 24 hours.

TABLE OF MILL RESULTS.

	No. of Holes in Grate or Screen.	Weight of Stuff ground in 10 Hours.	Approximate Horse-power.	Cost per Ton.
		Tons.		s. d.
Ordinary Crushing Mill Rolls, 21-inch diameter, speed of Rolls 42 feet per minute	0 to $7\frac{1}{2}$ mm.	25		0 $9\frac{1}{2}$
Ordinary Cornish Stamps per head	0 to 3 mm.	1	$1\frac{1}{4}$ per head	0 $11\frac{1}{2}$
Husband's Stamps, 1 head, 9 cwts.	Grate holes $\frac{3}{4}$ mm. diamtr.	13 to 15	16 ,,	
Elephant Stamps, 2 heads, each $4\frac{1}{2}$ cwts.	800 holes per square inch	6 ,, 7	$1\frac{3}{8}$,,	
Ordinary Californian Stamps	0 to $\frac{3}{4}$ mm.	2	$1\frac{3}{4}$,,	
,, ,, dry stamping	0 to $\frac{1}{2}$	1	$1\frac{3}{4}$,,	
Horizontal Mill	3600 holes per square inch		5 per mill	2 3
Chilian Mill			7 ,,	6 10
Arrastre			2 ,,	

(D.) *Sizing Apparatus.*—When the velocities of the fall of grains of stuff in water materially differ from each other, then the number of sizing and classifying divisions may be few; but when the specific gravities of several veinstones are closely allied to each other, then the classifying arrangements must include a greater number of subdivisions. The integrity of this principle should be strictly adhered to without multiplying the number of sizes beyond what may be requisite for economical purposes. Too great a refinement in the division of stuff will involve a needless complication in the machinery as well as undue cost for plant; on the other hand, neglect of the fundamental principle of sizing will most certainly entail unnecessary cost in dressing and loss of ore in castaways.

Sizing Plates.—The plates are made either of charcoal iron, puddled steel, cast steel, or copper. The dimensions vary with each metal, and with the thinness of the plates themselves. Plates perforated with holes from $\frac{1}{8}$ millimetre to 1 millimetre are about 3 feet long by $2\frac{1}{4}$ feet wide, while holes of

greater diameter are made in plates 6 feet long by 3 feet wide. Small holes from ½ millimetre to 1 millimetre require to be made one diameter apart; holes exceeding these dimensions may be closer together; above 5 millimetres diameter the distance need not exceed one-third of a diameter of the hole itself. The holes in sizing plates are strictly round and free from burr. For sizing stuff from ½ millimetre to 1 millimetre copper plates are often employed. Stuff from 1 millimetre to 50 millimetres is separated on plates of iron or steel. The holes in sizing plates run from ½ millimetre or one-fiftieth part of an inch to 50 millimetres or 2 inches in diameter. From ½ millimetre to 3 millimetres the diameter of the holes advances with a difference of ¼ millimetre, from 3 millimetres to 13 millimetres the increase is ½ millimetre between each several size, while from 13 millimetres to 50 millimetres it is 1 millimetre.

Fig. 204 illustrates portions of plates perforated with holes one, two, three, four, five, seven, ten, and fifteen millimetres diameter. These holes give a

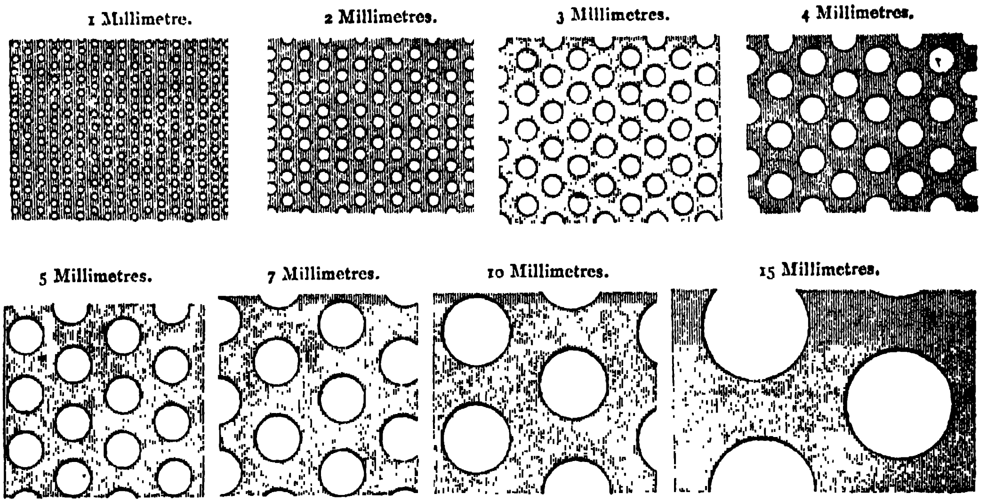

Fig. 204.

distinct idea of millimetre measurement, invariably used on Continental dressing-floors in defining the grain-size, or dimensions of stuff.

The annexed table affords particulars relative to thickness, weight, and measurement of plates pierced with holes ranging from 1 millimetre to 50 millimetres diameter.

The Continental definitions for stuff on the dressing-floors have no fixed and equivalent expressions among British miners; we must therefore be content to employ terms of an indicative, rather than of a determinate character. The designation, therefore, of stuff from 0 millimetre to ½ millimetre is, slime sand; from ½ millimetre to 1¼ millimetre, fine sand; from 1¼ millimetre to 3½ millimetres, coarse sand; from 3½ millimetres to 7½ millimetres, coarse grain stuff; and from 10 millimetres to 50 millimetres, rough stuff. Slime and fine sand, 0 millimetre to 1¼ millimetre, is divided by means of classifiers, whilst products ranging from 1¼ millimetre to 50 millimetres are sized by the use of flat sieves or trommels. Slime and fine sand are usually

treated on buddles, tables, or in jiggers; coarse sand and coarse grained stuff in jiggers; and rough stuff, partly in jiggers and partly disposed of by hand picking.

TABLE OF SIZING PLATES.

Iron or Steel Plates.				Copper Plates.		
Diameter of Holes in Millimetres.	Thickness of Plate in Millimetres.	Approximate Weight of Plate per Square Foot.	Maximum Size of Plate.	Thickness of Plate in Millimetres.	Approximate Weight of Plate per Square Foot	Maximum Size of Plate.
½	—	—	—	⅝	·6 lbs.	4 × 3 ft.
¾	—	—	—	¾	·8 ,,	
1	¾	·7 lbs.	3 × 2¼ ft.	1	1· ,,	5 × 3 ft.
1¼— 1½	1	1· ,,	4 × 2½ ft.	1⅛	1·1 ,,	
1½— 2	1⅛	1·3 ,,	4 × 3 ft.	1⅜	1·2 ,,	6 × 3 ft.
2¼— 2½	1⅜	1·5 ,,	5 × 3 ft.	1¾	1·5 ,,	
2¾— 3	1½	1·7 ,,		2	1·6 ,,	
3¼— 4	1⅝	1·9 ,,	6 × 3 ft.	2¼	1·8 ,,	
4¼— 5	1¾	2· ,,		2½	2· ,,	
5¼— 7	2	2·4 ,,				
7¼—10	2¼	3· ,,				
10¼—15	2¾	3·2 ,,				
15¼—25	3	3·5 ,,				
25¼—50	3½	4· ,,				

The diameter of the sizing holes usually employed for mixed ores, galena, blende, and spathic iron is for—

Rough and coarse grain stuff . .	15, 10, 7½, and 5 millimetres.
Coarse sand	5, 3, 2, and 1¼ ,,
Fine sand	1¼ to ½ millimetre.

In practice other divisions are employed, as will appear evident from a perusal of the following table, but in each mine it will be obvious that the sizing numbers approximate to those already stated, the difference being, perhaps, in some measure due to the necessity of enriching ore associated with gangue, in which there is but little difference in their respective densities.

TABLE GIVING THE DIAMETER IN MILLIMETRES OF HOLES IN VARIOUS SIZING TROMMELS.

Angleur, Belgium (lead glance, blende, and iron pyrites), 25, 20, 18, 16, 12, 10, 8, 6, 5, 4, 3, 2, 1, ½.
Commern, Prussia (lead glance and quartz). To crusher, 18—10; to jiggers, 8, 6, 4, 3, 2, 1; buddles and tables, ½—0.
Wildberg, Prussia (lead glance, carbonate of iron, and quartz). Picking-tables, 25—16; to jiggers, 10, 6, 4, 3½, 2; to fine sand jiggers, 1¼, ¾, ½; to buddles and tables, ½—0.
Lohmansfeld, Prussia (lead glance, blende, copper, and carbonate of iron). To jiggers, 20, 15, 10, 5, 3, 2; to stamps, 1; to jiggers and shaking-tables, 0, 1.
Alltgluck, Prussia (lead glance, blende, and carbonate of iron). To jiggers, 16, 12, 9, 6, 4, 3, 2; to tables, 1, ¾, 0.
Bad Ems, Prussia (lead glance). To picking-table, 30, 20; to jiggers, 13, 9, 8, 5, 3, 2, 1; to tables and buddles, ½, 0.
Berzelius, Prussia (lead glance and blende), 10, 8, 6, 4, 3, 2, 1, ½.
Iserlohn, Prussia (calamine, lead glance, &c.). To jiggers, 18, 13, 10½, 8, 6, 5, 4, 3, 2, 1, ⅝; to tables, ½, 0.
Mine in Linares district, Spain (lead glance). To jiggers, 10, 7, 5, 2½; to buddles, 1½, 0.
Burra Burra, South Australia (carbonate of copper, quartz, ferruginous clay). To jiggers, 18, 13, 10, 7½, 5, 3½, 2, 1½, ¾; to fine sand jiggers, ½, ⅜, ⅛.

The separation of stuff into grains of different sizes can be effected either by a combination of flat-bottomed sieves or by a set of revolving trommels. Flat sieves may be arranged for sizing purposes as a series of steps, fitted

within a long inclined trough or set in a rectangular frame; they may be also rendered movable or stationary. In the latter case the stuff must be mechanically agitated and passed across the plates. The angles at which movable sieves are set is usually about 18°, the length of stroke given to them 1¼ inch, and number of strokes per minute 200. The sizing effect can be produced either by a cam, shuttle, or crank, and any shock movement may be intensified by the use of wooden or steel springs. Flat sieves have been extensively employed in Austria; but of late years the dressing works of Prussia and Belgium have been almost entirely fitted with trommel sieves. The disadvantages attending the use of flat sieves lie (1) in the amount of dead weight to be moved for securing a given result; (2) in the difficulty of sizing the finer divisions of stuff without the agency of water; and (3) in certain complications due to cam, lever, or crank arrangements. On the other hand, flat sieves are replaced with facility, and the sizing, proceeding from large to small grains, leaves the thinner and more finely-perforated plates free to do their work effectively.

Although trommel sieves admit of simple arrangement in connection with the driving appliances, and consist of well-balanced parts, yet none of the several forms can be said to be strictly free from objection; simplicity is sometimes secured by inverting the sequence in which the sizing of the stuff is best performed, while if the proper order of separating the grains, that is, from the greater to the lesser sizes, is retained, it frequently happens that the apparatus requires a considerable height of ground, or that the result is only achieved by employing several concentric cylinders revolving on one common axis, which cylinders become difficult of access when wanting some very slight but necessary repair. In order to effect a thorough division of the grains by means of revolving trommels, water should freely enter into and fall upon the cylinders. The crushed stuff should therefore drop into a stream of water, and water should also be delivered to the outside of the trommels from distributing launders or pipes. The names given to trommel sieves accord with the work they perform; as, for example, *clearing trommel*, for clearing vein stuff of associated clay and earthy matter; *separating trommel*, for dividing fine and coarse-grained stuff for the sizing trommels; *sizing trommels*, for sizing stuff for jiggers and buddles; and *draining trommels*, for ridding sand of water. Cylindrical sizing trommels require to be set at angles varying from 3° to 5° in order to pass the stuff from the entering to the discharging end. The axis of a conical-shaped trommel may be strictly level, since the falling angle of the perforated shell, usually about 3°, combined with its rotative movement, will suffice to impel the stuff from the smaller to the larger end.

Hand Riddle.—The simplest form of sizing apparatus is the hand riddle, which is formed of a hoop of oak 18 to 20 inches diameter, ⅜ of an inch thick, and 6 inches deep. The bottom consists of a meshwork of copper or iron wire of a gauge suitable for the intended work.

Circular Hand Riddle.—This riddle consists of a cylinder of wirework mounted in a frame with a handle at its lower end. The meshes of the sieve when applied to riddling copper ore vary from ¾ to 1 inch square, according to the character and quality of the vein stuff to be separated.

Continuous Cylindrical Trommel.—This trommel is shown in Fig. 205. The stuff entering at the farther end from the driving-rigger, passes to the ½ millimetre section, then successively over the ¾, 1½, 2, and 3 millimetres divisions. The thin plates are supported by lateral bars fastened to the rings within and without the cylinder, one of such bars being shown. Wrought-iron rings about 1½ inch wide and ¼ inch thick divide the cylinder into sections, and serve as fasteners for the plates and for connecting the radial arms proceeding from the central bosses. The order in which the sizing is effected in this trommel sieve is from small to large grains; consequently, the initial quantity of stuff passes first over the thinnest plate, and, in the absence of careful feeding, the fine ½ millimetre holes may be overcharged, when an imperfect sizing will be the result; on the other hand, the separation being performed on a continuous line without a material loss of fall, this trommel is a useful one for many dressing-floors. The angle at which these trommels should be set is from 3° to 5°. The diameter of the trommels runs from 2 to 3 feet, the number of revolutions per minute from 18 to 25.

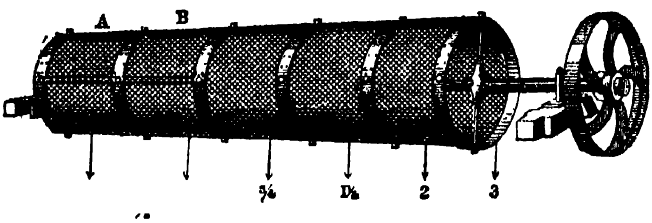

Fig. 205.

Continuous Conical Trommel.—This trommel includes different sizing divisions, but instead of being a true cylinder the form of the perforated shell is that of a truncated cone, running from the axial line at an angle of from 3° to 4°. The sequence in which the sizing is effected is the same as in the continuous cylindrical trommel.

Single Conical Trommel.—The trommel, Fig. 206, may form one of a set for sizing stuff from a clearing trommel or crushing mill. The order in which the sizing occurs will be from great to small grains, hence the thinnest plate and smallest holes will be subjected to a minimum amount of wear. A system of six trommel sieves, each 42 inches long, diameter at large end 21 inches, and at small end 18 inches, making 20 revolutions per minute, will size from 20 to 30 tons in 10 hours. The water required for the six trommels will be from 12 to 15 gallons per minute. In order to convey the stuff from one trommel to another, a sheet-iron or wooden hopper may be employed. When a set is fixed step-like, one above another, on a running angle of, say, 40°, the driving gear may consist of a shaft and bevel wheels; but the necessary motion may also be communicated by a light side-rod and cranks, in connection with a small fly-wheel. At Angleur, in Belgium, where the stuff from the clearing trommel is divided by seven trommels into

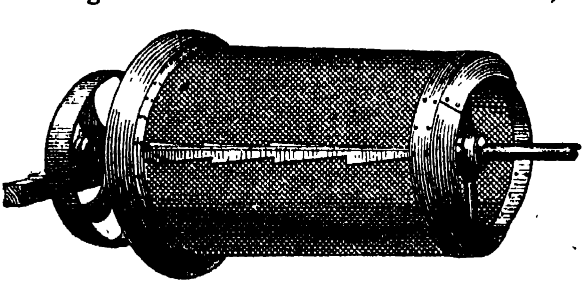
Fig. 206.

fourteen sizes, each sizing trommel is 20 inches diameter and affords two divisions of stuff, viz. front division, 25, 20, 14, 10, 5, 3, 1 millimetres; back division, 60, 16, 12, 8, 4, 2, ½ millimetres. Some single trommels, designed by Darlington, for sizing coarse-grained stuff and sand, have a diameter of 24 inches at the small end and 28 inches at the large end, with a sizing length of 38 inches, and make 20 revolutions per minute. The sizing capacity of a group of 10 trommels making 20 revolutions per minute is about 8 tons per hour. The preference for cascade or step-like trommels is due to several features, among which may be noticed that the sizing takes place in the proper sequence of numbers, that is, from large to small grains. Each trommel usually excludes but one sort of grains and passes all grains smaller than the sieve-holes through the latter, whereby a better separation is effected than with continuous trommels numbering several divisions. Large grains do not pass over the fine-hole sieves, and cause undue wear. Each trommel is light, portable, and cheaply duplicated and replaced. Against these manifest advantages, however, must be placed the many parts necessary for driving a system of trommels and the loss of fall arising from the descent of stuff from one trommel to another.

Double Conical Trommel.—For the purpose of obtaining three distinct separations of stuff in a short length, and without incurring much loss of fall, two concentric conical trommels are employed. Their use is, however, not so much for sizing as for dividing stuff for the sizing trommels.

Continuous Conical Trommel.—With the view of lessening the fall incident to single sizing trommels minimising friction, and securing the proper order in which the sizing operation is best performed, continuous trommels have been designed by Rittinger, Huet, Geyler, and others. Darlington and Green have also arranged a series of conical trommels without much loss of fall, and well adapted for sizing lead or copper ores.

TABLE OF PARTICULARS RELATING TO SPEED, DIMENSIONS, AND LENGTHS OF CONTINUOUS TROMMELS USED AT VARIOUS MINES.

Name of Mine.	Diameter of Trommel in Inches.	Revolutions per Minute.	Length of each Sizing Portion of Trommel in Inches.	Length of Trommel in Feet.	Diameter of Hole in each Length of Trommel in Millimetres.
Berzelius . . .	32	14	48, 36, 24, 14	10	¾, 1, 2, 3
,, . . .	32	14	30, 26, 18, 16	7½	4, 6, 8, 10
Altgluck . . .	36	12	40, 30, 27, 21, 17	11¼	4, 6, 9, 12, 16
,, . . .	36	12	37, 38, 36, 32	12	¾, 1, 2, 3
,, . . .	36	12	33, 22, 20, 13, 13	9	¾, 1, 2, 3, 4
Lohmansfeld . .	24	30	24, 24, 24, 24	8	20, 15, 10, 5
,, . .	24	30	24, 24, 24, 24	8	15, 10, 5, 3
,, . .	12	—	24, 24, 24	6	1, 2, 3
Wildberg . .	22	20	30, 30, 30	7½	1¼, 2, 3¼
,, . . .	24	20	30, 30	5	½, ¾
Iserlohn . . .	36	12	38, 22, 28, 24, 19	11¾	6, 7½, 10, 13, 18
,, . . .	36 conical.	10	34, 29, 35, 21, 18	10½	½, ¾, 1¼, 2, 3¼
Burra Burra . .	12	30·48	21, 24, 27, 30, 36	11½	18, 13, 10, 7½, 6
,, . . .	12	30·48	23, 27, 29, 34, 48	13½	3¼, 2, 1¼, ¾, ½
Minerzhagner. .	9	32·48	36, 36, 30, 18	10	6, 6, 10, 18
,, . . .	14	30·41	30, 33	5½	1, 1
,, . . .	12	30·48	54, 42, 36	11	7, 8, 9
,, . . .	12	30·48	42, 36, 36, 36	12½	4, 6, 8, 10
,, . . .	12	30·42	39, 39	6½	3, 2

(E.) *Classifying Apparatus.*—Fine sand and slime claim the especial attention of the dresser, seeing that the quantity in some dressing works is often very considerable, and in many instances exceeds that of the coarser stuff produced. The isolation of finely divided ore from sterile sand is but seldom accomplished direct, some preparatory treatment being necessary so as to bring the grains within the scope of particular concentrating apparatus. Connected with the enrichment of fine sand or slime it may be observed—

1. When light particles are suspended in water, the natural resistance opposed to the freedom of their descent is affected by the slightest current in the water itself or by the contact of particles among themselves, either circumstance modifying the direction that each separate grain would take if it were permitted to obey the simple action imparted to it by its own specific weight, and preventing it from obtaining the position due to it from the action of gravity alone.

2. The form of the particles may under certain circumstances be a cause of derangement, and may acquire an influence all the more important from the minuteness of the grains themselves. As an example, thin scales of sulphide of lead and malachite are known to float on the surface of water in spite of their natural densities.

3. Particles of sand, so minute as not to settle readily in water, or when settled agglomerate into a tenacious slime, must occasion a loss of orey constituents, as well as much labour in the enriching process.

The great waste, cost, and difficulty attending the dressing of fine sand slime render it, therefore, of the highest importance to arrange continuous working apparatus, so as to lessen the item of labour, and to pass the stuff from one stage of treatment to another while it is freely suspended in water, in order that the ore may be the more readily concentrated in the various machines.

As sizing trommels for fine slimes are altogether useless, and as the effects due to specific weights are less readily under control with the diminishing size of the particles, it has been found necessary to effect a classification of grains by bringing other principles to assist the density of the grains themselves. In order, therefore, to effect the concentration of classified grains, advantage is taken of the greater or less amount of frictional surface which they offer to a stream of water flowing over flat or slightly inclined tables, such as buddles and frames.

The difference in the density of particles composing a mixture of stuff will also assist in the separating process, for with regard to two bodies the volume of each being equal, but of a different density, the frictional surface on a table, although the same, will in the lighter substance offer less retarding action than the heavier one; the former will, consequently, move more rapidly than the latter and separate from it. In addition, the smaller a grain or particle is, the more important will the surface become in comparison to its specific weight, and the difficulty of separating ore from gangue will also increase in proportion as the grains become finer, since the resistance to movement depending on weight decreases more rapidly than that of the influence exercised by the current on the surface of the particles.

The grains submitted to the action of stream and classifying apparatus

may vary in their dimension from 0 to 1½ millimetre. In continuous stream cylinders only two classes of sand are usually produced, but classifying troughs will afford a separate classification for each of its divisions, while a set of classifying cones will give a distinct class of grains for each distinct cone.

The oldest classifying arrangement is the labyrinth, or settling-pits. To three coffers containing nine stampers, four pits were formed, each of which increased in width from 1, 1¼, 1½, to 1¾ foot, and in length from 15, 21, 24, to 36 feet, with inclinations in the same sequence of ½, ¼, and ⅛ inch per foot, the floor of the largest being horizontal. Such a system of pits classified the stuff into four sets of grains, the coarser grains being lodged in the first or narrowest pit. This classification was, however, never very perfect, besides which the method entailed some expense in clearing the pits and in preparing the products a second time for further treatment. In addition, the loss of fine sand was generally from 10 to 15 per cent. of the initial weight.

Separating Cylinders.—In this apparatus a simple division of the sand is effected by maintaining the influx at a greater height than the efflux of a stream of water, thereby producing an upward hydrostatic pressure. The sand and water are introduced between an outer and inner cylinder, clean water is added through the inner cylinder, when fine sand and water will escape through the annular space between the two cylinders, while the heavy grains may flow through a small pipe in the bottom of the cylinder about ¾ inch in diameter. This pipe is provided with an adjusting plug or slide for regulating the proportion of stuff to be discharged both at the top and bottom of the apparatus. The cylinders may be formed of sheet zinc,

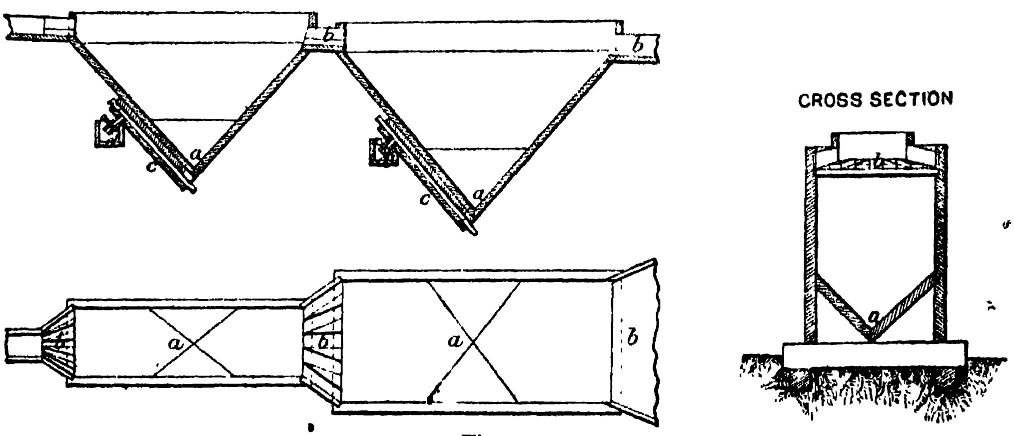

Fig. 207.

the short central one (say) 7 inches in diameter, the other two respectively 8 and 9 inches in diameter. The length of the outer cylinder may vary from 4½ to 5 feet.

Pyramidal Troughs, Fig. 207, as their name implies, are hollow, rectangular, pyramidal boxes. They are usually constructed of strong boards well joined together. The sides are inclined at angles of not less than 50°, and there is a small hole in one side close to the apex. They are fixed

horizontally in an inverted position, and the crushed material is introduced at one of the narrow ends, a few inches below the top, by means of a launder. The result is that, as soon as the box is filled, a certain portion of the crushed matter, *i.e.* the coarsest and heaviest, which the water on account of its diminished velocity is not able to carry farther, sinks and slides down the inclined sides of the pyramid and escapes through the small hole *a* near the apex, whilst the finer and lighter matter passes off at the top by an outlet *b* in the centre of the end opposite to the point of entrance. If now a second larger box be attached to the first, a third still larger one to the second, and so on, each succeeding box at a slightly lower level, in order to prevent any settlement of stuff in the passage ways, it follows not only that the same process of settling and escaping of the particles from the apex will take place in every box, but also that their size will decrease nearly in inverse proportion as the surface of a succeeding box is larger than that of the preceding one, or directly as the velocity of the water is diminished in it. According to this principle of the boxes, if they were made of only very gradually increasing size, and the apex holes proportionately small, it would be possible to classify the stuff into several sets of equivalents before it entirely settled, *i.e.* till clear water passed off from the last box. Experience has, however, shown that for fine-ore dressing in general, classification into four different sizes by an apparatus of four boxes is quite sufficient. The size of the different boxes, in order to insure the most perfect classification, depends both on the amount of material which has to pass through them per second and the size and character of the grains, and by theory and practice it has been found that for the supply of every cubic foot of material the width of the first or smallest box must be $\frac{1}{10}$ foot, *i.e.* for instance, for 20 cubic feet 2 feet, and for every succeeding box it ought to be about double that of the preceding one, or, generally, the widths of the boxes must increase nearly in geometrical progression 2, 4, 8, &c., and their lengths in an arithmetical one 3, 6, 9, &c. Their depths depend on the angle of inclination of the sides, which, as already stated, is generally 50°, because, if less, the stuff would be liable to settle firmly and choke the central orifice, and, if larger, unnecessary greater height of the boxes would be required. The form of the two smaller boxes is commonly such that the two short sides are inclined at the above angle, and the two long ones which would become far steeper are broken, *i.e.* are for a certain depth from the top vertical, and afterwards inclined at the normal angle. This modification has, however, no influence upon the action of the boxes, but simply facilitates somewhat their construction and firm fixing. The sides of the larger boxes are generally even throughout. The way in which the outlet-holes *a* at the apices are constructed has an important bearing on the operation of the boxes. At these points the hydrostatic pressure is considerable, and the holes would naturally be kept small in order to prevent too much water passing with the particles of stuff; such small outlets are, however, especially in the treatment of coarser material, very liable to become choked. This difficulty has been met by the holes being made of conveniently large size, but connected with pipes, *c*, $\frac{3}{4}$ inch in diameter, which rise up the sides of the boxes, *i.e.* of the smallest box to within 3—3½ feet, and of the others to

within 2—2½ feet from the top, and are there furnished with small mouthpieces *d*, supplied with taps for regulating the outflow. This arrangement, on account of the outlets being so much higher, has the further advantage that a considerable amount of fall is gained (especially as regards the large boxes) which for the subsequent treatment of the material is in some cases of special value. There are two more points that require attention in order to insure good action of the apparatus, namely, the introduction of the material into the different boxes equally and without splashing, and, further, to prevent the entrance of chips of wood, gravel, or other impurities that are likely to stop or otherwise obstruct the outlets. The first point is met either by having the supply-launders expanded fanlike and furnished with dividing ledges, *b*, or by the interposition of small troughs, the sides of which, nearest the box to be supplied, are perforated near the bottom by equidistant small holes. The cleaning of the material previous to its entering the first box is generally effected by the main supply-launder being made a little wider near the point of entrance, and the insertion at this place of a fine wire sieve across the launder, and somewhat inclined against the stream. This sieve must be occasionally looked after to remove any impurities collected in front, and this, in fact, is the chief attention the whole apparatus requires, for otherwise it needs hardly any supervision; if once in proper working order its action is constant and uniform, provided the material introduced does not change in amount and quality; and it has this further advantage, as compared to the slime labyrinths, that the classified stuff can from the outlets be directly conveyed in small launders to the concentration machines for treatment without any previous preparation. One point, however, not in favour of the apparatus is that, having to be placed between the reduction mill and the concentration machines, a great fall of ground is required to permit the direct introduction of the material, and also to allow sufficient fall for the tailings; and thus, where local circumstances are unfavourable, it has to be erected at a higher level and necessitates the use of dipper wheels or other suitable appliance for lifting the stuff. The action of the different boxes on certain slimes, with regard to the percentage of fluid matter and the quantity and character of the solid contents respectively separated, was, according to some experiments, as follows:—

The small box separated 38—40 per cent., which contained per cubic foot 16—18 lbs. coarse sand.

The second box separated 20—22 per cent., which contained per cubic foot 13—14 lbs. fine sand.

The third box separated 18—20 per cent., which contained per cubic foot 15—16 lbs. coarse slime.

The largest box separated 10—12 per cent., which contained per cubic foot 10—12 lbs. fine slime.

Triangular Double Troughs.—Another method of classification, effected by means of double triangular troughs, "Spitzlutten apparatus," is based upon the principle that if material composed of particles different in size and density is exposed to a rising stream of water, the velocity of this stream may be so regulated that particles of certain size and character (equivalents) sink, and may be conveyed to concentrator, whilst the remainder is carried

upwards. Consequently, by repeating this operation a certain number of times with a gradually decreased velocity of the rising stream each time, the material can thereby be separated into as many different classes of grains.

The troughs, Fig. 208, by which this action is produced are constructed as follows: Within a triangular trough *a* of certain length and width, with two opposite sides vertical and two inclined at angles of 60°, is a similar small one *b* having the vertical sides in common with the larger trough, but its inclined sides fixed at certain equal distances from and parallel to those of the latter. There is thus an open V-like space *c* left between the inclined sides of the two troughs, representing, as it were, a rectangular pipe sharply bent in the centre; and it is through this that the stream of material has to pass, *i.e.* to fall and rise. The velocity of the stream depends on the size of this space, and also the size of the particles that will rise or sink in it. The cross section and respective

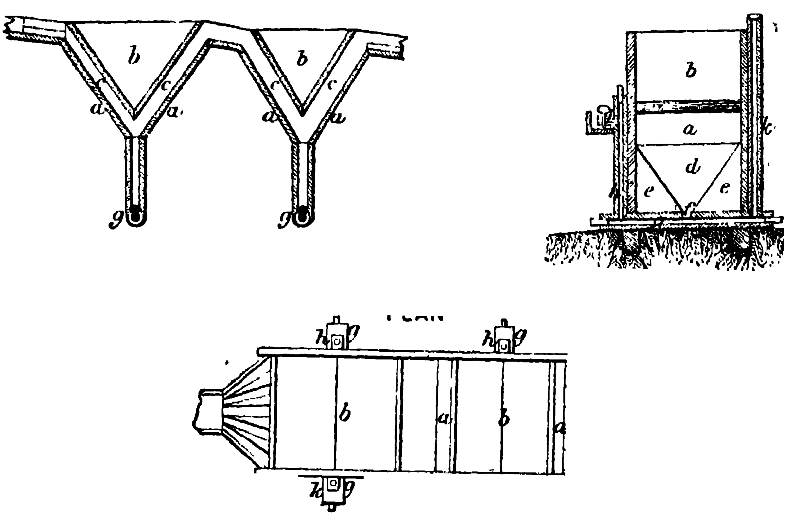

Fig. 208.

velocity stand in inverse relation to each other, and their determination for each double trough of a complete apparatus is a matter of mathematical calculation in which the size of the largest particles and the specific weight of the material to be classified form the main figures. For ores crushed so fine that the largest grains are not more than 0·6 millimetre in diameter, the most satisfactory classification into four different kinds of grains is arrived at by a series of four double troughs, with the velocity of the stream decreasing from the first to the succeeding troughs, in the progression of 2·3, 0·94, 0·37, 0·15 inches per second, and if the width of the channel for the first trough is 1·1 inch, and its length 2 feet, the dimensions of that of the second trough follow as 2·75 inches is to 2 feet. And as it is not advisable to increase the width of the channels beyond 3 inches, the channels of the third and fourth troughs are each 3 inches wide, and respectively about 54·5 inches and 135 inches long. The mean depth of the channels, measured from the line of inflow of the material to the lowest part of the inside trough, is for the

two smaller double troughs about 3 feet, for the two larger ones from 4 to 6 feet. In order to carry off the coarse particles that sink in the channels, the inclined sides of the outside troughs do not meet below, but are continued downward, forming a long and narrow pyramidal opening *d*, about 1½ inch wide at top. The short sides *e e*, slope inward at an angle of not less than 50°, contracting the opening to a small hole *f*, of about 1 inch square at bottom, through which the material is discharged into an horizontal pipe *g*, cross section, that extends both ways a small distance beyond the sides of the apparatus, and is connected at the ends with vertical 1-inch pipes. One of these, *h*, serves for the outlet of the classified material, and is carried up to within 36 to 21 inches of the water level in the channel *c*, according to the degree of fineness of the particles that have to pass through it (the same as in the pyramidal boxes). At the top it is supplied with a tap for the regulation of the outflow. The other pipe *k*, cross section, conveys a supply of clear water furnished from a launder, *l*, supplied with a tap *m*, and as the water in the pipe stands 6 to 8 inches above the water level in the trough a small uniform pressure is produced, causing a forced influx of water at the point *f*, which is essential for good classification. This water opposing itself to the downward current charged with sediment in the pyramidal channel *d*, prevents all but the coarser particles and pure water passing into the pipe *h*, and thus only grains of the desired size are carried to the outlet *i*. With regard to the relative positions of the different double troughs of the series, they are fixed exactly horizontal, and sufficiently below each other to prevent any settlement of material in the communication launders, which are necessarily very broad. Other particulars regarding proper working, supervision, &c., are the same as those given for the pyramidal boxes. According to experience a series of four of these double troughs classifies as well, and for the two coarser kinds even better and cleaner, than a set of four pyramidal boxes, though for the fine slimes the latter are generally preferred, as they effect the desired settlement of the stuff more completely. A complete apparatus of troughs requires also less fall and space than one of pyramidal boxes, and is more easily regulated in cases of increased or diminished influx of material. As regards the results of classification by the different troughs of the series, they are approximately stated as follows: The first or smallest trough separates from the material supplied about 30 per cent. coarse sand; the second trough about 25 per cent. fine sand; the third, 20 per cent. coarse slime; the fourth, 15 per cent. fine slime.

Classifying Launder.—In some dressing works, fine sand from the top of classifying cylinders, and from fine-grain sizing trommels, flow into an expanding launder, in which the particles are classified and collected according to their equivalents. The total length of one of these classifying launders is 28 feet 4 inches. The trough, including the first four divisions, 10, 13, 17, and 22 inches wide respectively, is 3 feet deep and 6 feet 8 inches broad at the top, with one side set at an angle of 45°, the other at 60°. The second, connected with the first trough, contains five divisions, each 29, 39, 52, 67½, and 88½ inches wide, 7 feet 7 inches broad, and 4 feet deep. The stream launder at the entrance of the slime water is 10 inches wide and 4 inches deep. From this point to the further or outflowing end the width is gradually

increased to 36 inches, and the depth to 18 inches. Along the bottom is a continuous opening ¼ inch wide. The water launder which carries the stream launder is 40 inches wide and 6 inches deep, and is pierced with plug-holes 1 inch in diameter.

The gradual widening of this launder occasions a corresponding decrease in the velocity of the stream and a deposit of grains in the several hutches according to their respective equivalents. This necessary result is assisted, and subject to modification, by allowing more or less clear water to pass

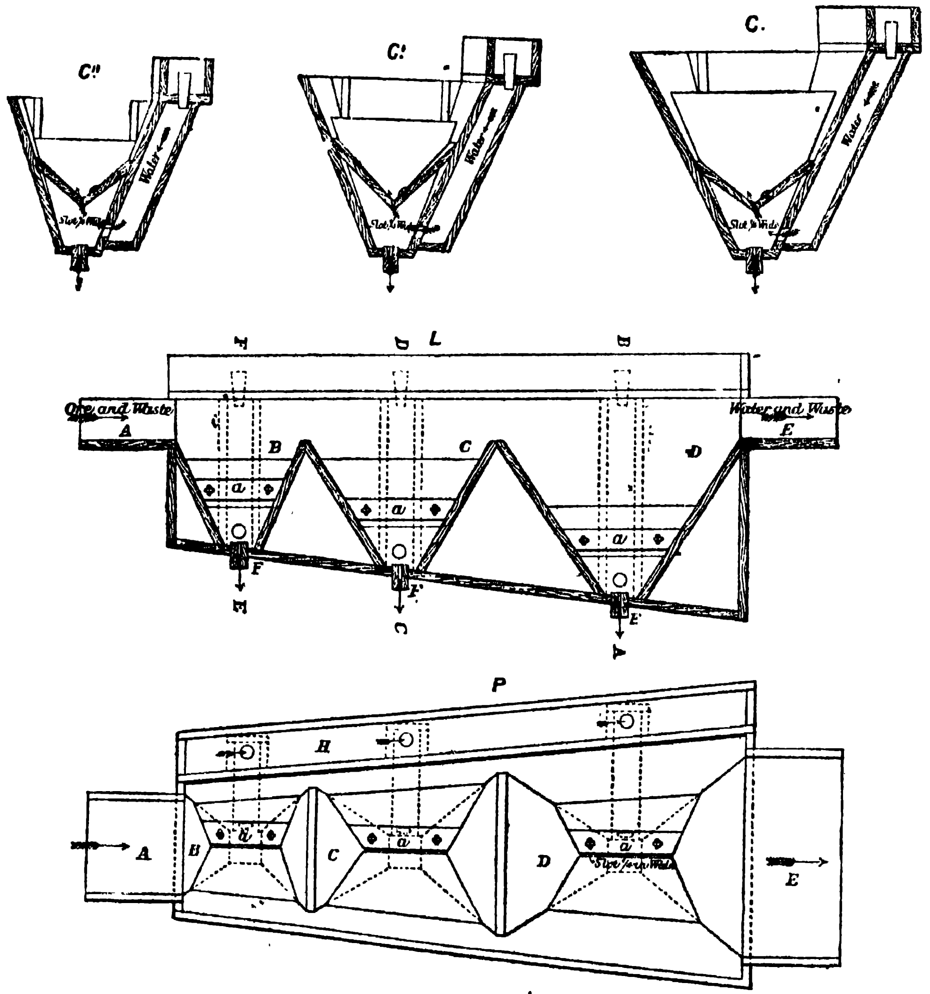

Fig. 209.

through the plug-holes. The distance between each plug-hole in the water launder is progressively greater as the stream launder widens. This feature is one of great moment, inasmuch as the volume of water is thereby lessened with the decrease that occurs in the equivalent value of the grains. A small classifier, made of wood, for classifying grains of lead, copper, or tin ore is shown in Fig. 209: L, longitudinal section; P, plan; C'', cross section on line of longitudinal section; E, F, C', second cross section on line C D; and C'', a third cross section on line A B. The launder A into

classifier is 11 inches wide and 5 inches deep, the narrow end of classifier is 16 inches and the wide end 30 inches wide. The discharge launder, E, is 24 inches wide. The first compartment, B, is 16 inches, the second, C, 24 inches, and the third, D, 30 inches long. Clean water is admitted into the classifier through plug-holes in the side launder, H, while the equivalents and a certain quantity of water pass through long slot openings adjusted

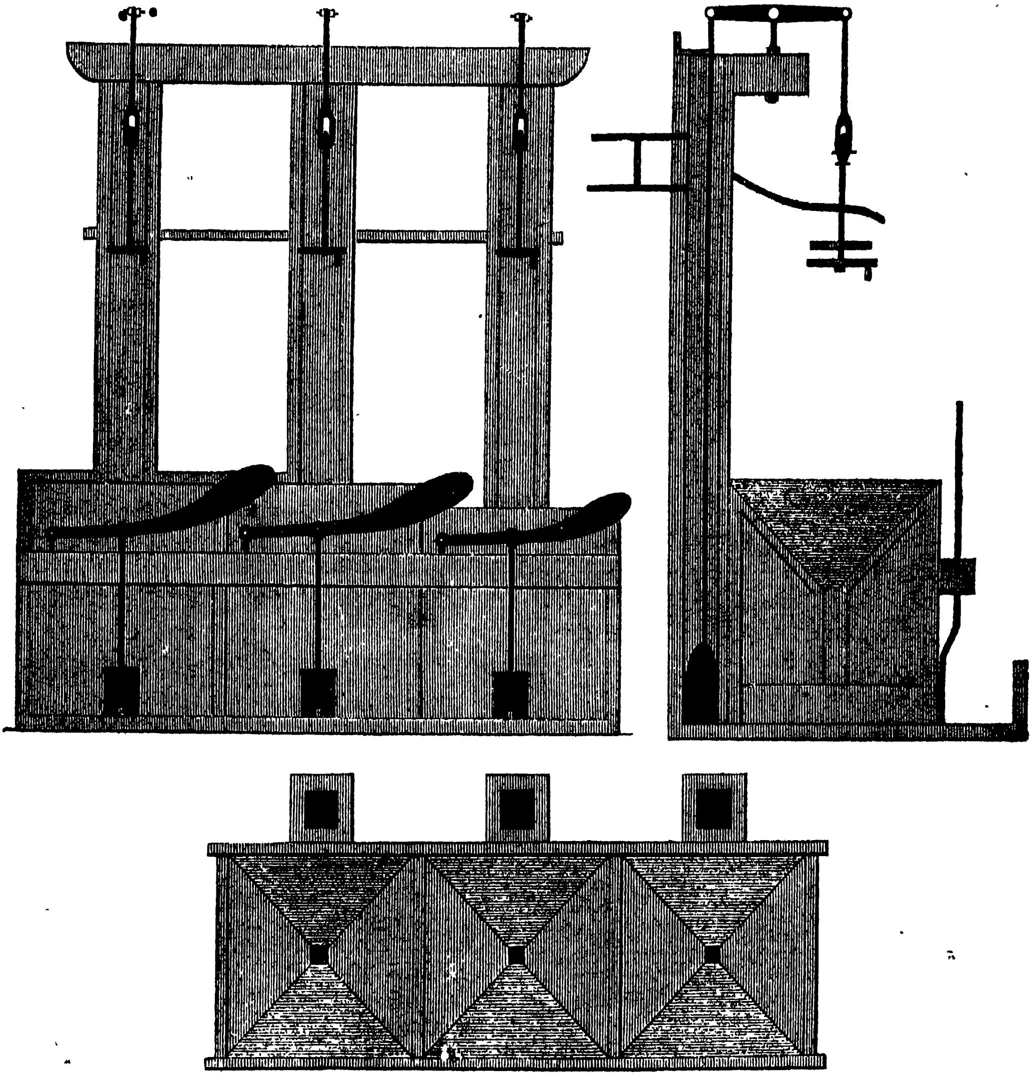

Fig. 210.

by plates, A, set near the bottom of each receptacle. The outlet-pipes at the bottom of the receptacles are formed of wood, the holes being ⅛ to ⅜ inch diameter. The course of the clear water and outflow of stuff is shown by small arrows on the transverse sections. Wood plugs serve to regulate the volume of water which passes into each receptacle.

Hodge's Classifier.—The inventor claims for this apparatus (Fig. 210): first, the machine is self-acting, and is cheaply maintained; second, a small

The number of sieve compartments in a jigger must depend in a great measure upon the quality and composition of the stuff to be jigged. In cases where only one ore is associated with the gangue a jigger 6 feet long will generally be sufficient; but when two or three ores are associated together with several varieties of veinstone a greater length will be found advisable. In enriching tin stuff or other valuable products a considerable length of jigging sieve might be advantageously employed.

The motion given to fine-sand piston jiggers need not be a variable one; in fact a differential movement is of no advantage in a quick, short stroke. In many dressing works the piston is reciprocated by means of eccentrics, in others by a rocking and counter shaft, while a third movement is produced by a revolving disc. Each device usually includes a means for varying the length of the piston stroke. The gear for driving a group of jiggers should suit the circumstances under which the latter must be worked. If the machines are to stand within a closed building belts may be employed, but if exposed to weather common shafting and wheel gearing will be preferable.

During the earlier use of continuous jiggers perforated plates were considered necessary, but experience has shown that wire-wove sieves offer the advantage of greater waterway and less resistance to the movement of the piston. For discharging the stuff from the collecting-boxes many methods are employed. Conical valves are much in use, but slides, Fig. 215, and plugs handled from the outside are equally effective. To adjust the thickness of sand on the ore beds in cascade sieves slides are occasionally fitted to the dividing bridges.

In fixing and working continuous jiggers the following points should be observed:—

Fixing.—Fix the jigger so that the sieve bottoms may be nearly level.

Sizing.—Size or classify the sand, and thoroughly free it from slime before passing it to the jigging-sieves.

Sieves.—Sieve bottoms may be of perforated plate or wire-work. Openings in sieve bottom for sand, $\frac{3}{4}$ to 1 millimetre grain size, must be greater than the grain dimensions of the stuff to be treated.

Beds.—Ore grains composing the beds must be larger than the openings in the sieve bottoms. Thickness of beds must depend upon size and richness of stuff to be jigged.

Hand Jigging Sieve.—This sieve is formed of a hoop of oak 18 to 20 inches diameter, $\frac{3}{8}$ inch thick, and 6 inches deep, while the bottom usually consists of a screen of copper or iron wire. Sometimes, however, a perforated copper plate is employed, when the sieve is termed a "copper bottom." The sieve charged with a thin bed of ore and orey stuff is placed in a cistern or tub of water and vigorously jerked until the sterile veinstone is separated from the orey mixture. The waste is then removed with a sheet-iron scraper, and the enriched ore is obtained.

Dillueing Sieve.—This sieve, either made with a horse-hair or canvas bottom, is chiefly used for effecting the final removal of any waste which may be present with the ore.

Brake Jigger.—The brake jigger consists of a trough or "hutch" through which flows a small stream of water. Over the centre of the hutch is suspended

a rectangular-shaped sieve, having about 25 holes per square inch, upon which is spread a bed of coarse ore about ¾ inch thick. The stuff to be jigged is placed upon the bed, when the sieve is lowered into the water by a lever, to which a jerking motion is given by the hand for two or three minutes. A connecting-rod at the back end of the lever passes through an eye in the end of an upper lever which carries the sieve, and which connecting-rod has a stop fixed upon it both above and below the end of the lever. Between these stops there is a certain amount of play for limiting the range of the jerking movement. On jerking the hand-lever up and down the heavier pieces of ore settle to the bottom of the sieve. When the stuff has been sufficiently jigged the sieve is raised out of the water, and the light particles on the surface, which contain little if any ore, are skimmed off and thrown away, while the middle part is laid aside for further treatment. The "bottom," comprising best ore

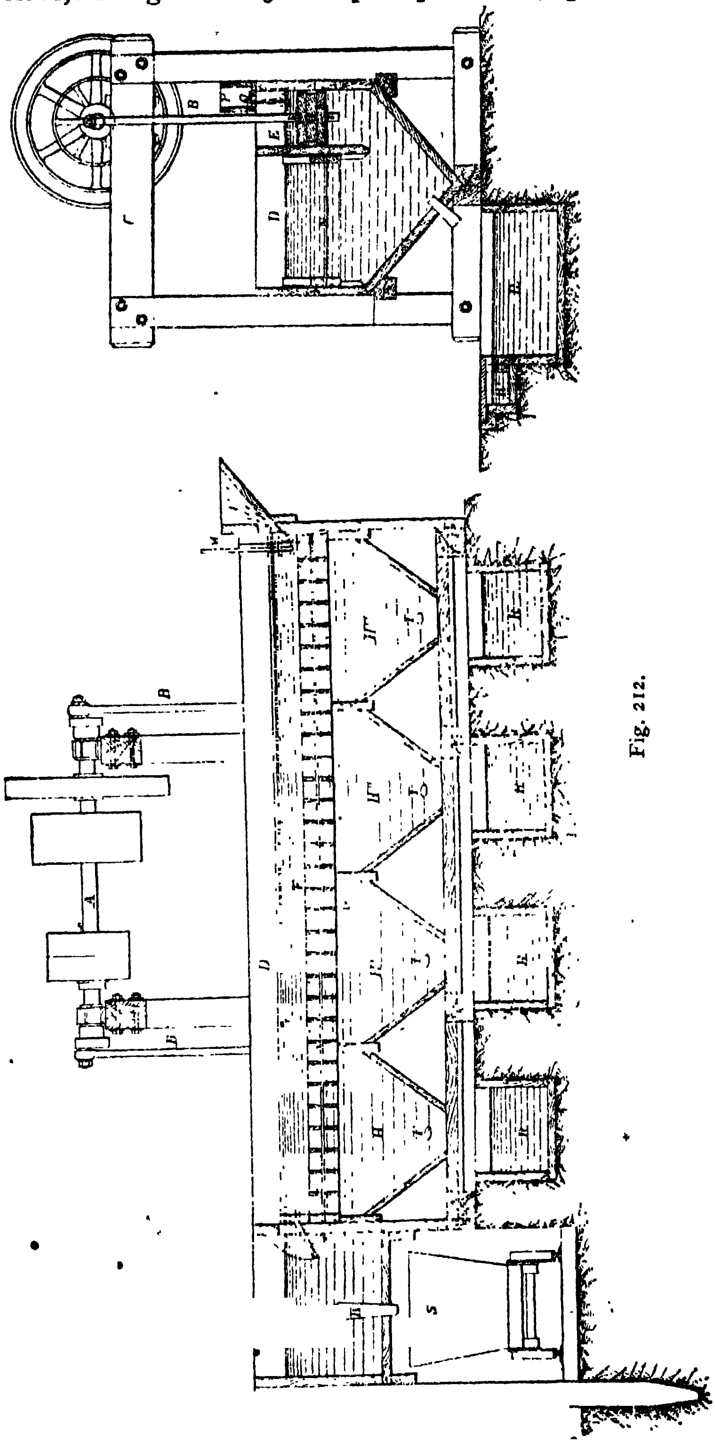

Fig. 212.

as well as the smaller particles which have fallen through the sieve and into the hutch, are usually sufficiently rich for the smelting furnace.

Coarse and Fine Sand Continuous Jigger.—Fig. 212 shows a continuous

jigger, which is successfully applied to the enrichment of both coarse and fine sand. Instead of separate sieves placed one below another, one long and slightly inclined sieve is employed. This sieve, supported on a wooden grid, is covered with a second grid of similar construction in the compartments of which the bed is lodged.

Underneath the sieve the ore and dredge receptacles are placed, and at the end of the hutch is a waste-box fitted with a launder for the escape of the water. The bottom edge of this launder is from 2 to 3 inches above the level of the sand, supposed to be in the jigger. The jigging or separation of the stuff is consequently performed under water, and any fine slime which the stuff may contain floats and leaves the grains of which the stuff is composed free to separate, fall, and arrange themselves according to their respective densities.

A jigger 20 feet long provided with a sieve 42 inches wide will despatch approximately—

Stuff composed of grains 3 to 5 millimetres diameter, 5 tons per hour.
" " 2 " 3 " " 3 " "

A, driving gear; B, adjustable eccentric piston-rods; C, frame work; D, sieve compartment; E, piston compartment; F, ragging frame; G, grid frame supporting sieve; H H′ H″ H‴, ore-boxes; J, waste-box; K, plug for discharging waste-box; L, feed hopper; M, slide for adjusting rate of feed; N, wire-work bottom; O, hole in launder; P, partly covered with a loose slip of iron for admitting water to jigger; R, ore-boxes; S, waste waggon; T, plug-holes for discharging ore from boxes; H H′ H″ H‴,—R′, launder for taking off the overflow of water from the ore-boxes R.

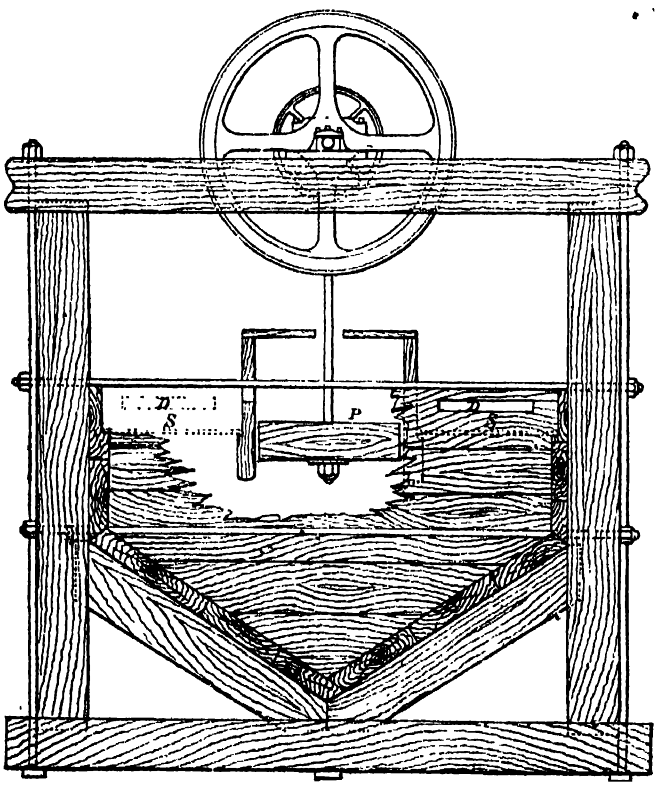

Fig. 213.

Argall's Jigger.—The piston in this jigger, placed between two hutches, is in free communication with two sieves, S S, Fig. 213. Two sizes of ores may be jigged at the same time, *i.e.* through No. 53 Cornish gauge, on one side of the piston, and through No. 25 on the other side—P, piston; S S, sieves; D D, discharge openings. The hutch is built in and supported by a frame of wood, to which it is securely

bolted. This frame extends above the hutch and carries the eccentric shaft and gear.

This machine, with a "four-hole" sieve, and a speed of a hundred and fifty revolutions per minute, will jig from 5 to 6 tons of coarse-grained stuff per hour. The pistons are hung to eccentrics.

Gear is fixed to carry off the dredge as it accumulates, while similar gear is attached to keep the bed at a constant level. The waste passes from the end of the machine into a waggon, while the concentrated ore is continuously discharged from the hutch.

The jigger, Fig. 214, shows the method of constructing these machines in

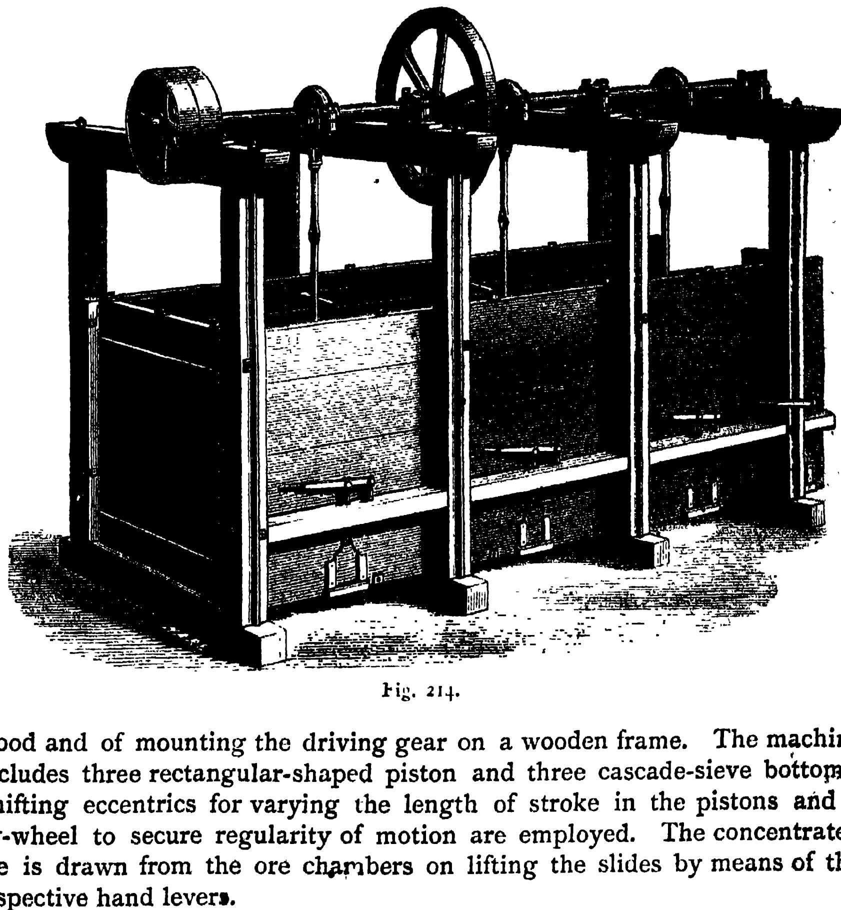

Fig. 214.

wood and of mounting the driving gear on a wooden frame. The machine includes three rectangular-shaped piston and three cascade-sieve bottoms. Shifting eccentrics for varying the length of stroke in the pistons and a fly-wheel to secure regularity of motion are employed. The concentrated ore is drawn from the ore chambers on lifting the slides by means of the respective hand levers.

Collom's Jigger.—This may be designated a tappet jigger, since the pulsating action is produced by two pistons, each rod of which is struck alternately by the "tap" of a rocker, and raised by a spiral spring around the piston-rod, which spring brings the piston up against an adjustable stop. The length of stroke given to the piston varies from half an inch to one inch, while the apparatus may be speeded so as to jig stuff of different degrees of fineness. The rocker is, however, usually worked by a crank making about 120 revolutions per minute. The space under each piston is in communica-

tion with one of a pair of hutches, F, Fig. 215. On the top of each hutch is fixed a fine sieve of brass wire, C, upon which is a bed of coarse ore about ¾ inch thick. The stuff to be jigged, supplied through a launder, Z, with a stream of water, is delivered upon one end of the sieve through a distributing grate, the sieve C is set with a slight fall towards the opposite end. The hutches are kept constantly filled with a supply of clear water with a pressure of 2 feet of head or upwards by the pipe between the two launders Z Z. There is also a constant overflow of water from the lower end of the sieves, carrying away the lighter stuff that is separated by the jigging process. The tappet action of the pistons gives a sharp quick motion to the water under the sieves, driving it up and through them, producing the same effect in separating the stuff upon the sieve as in the ordinary jigging-machines where the

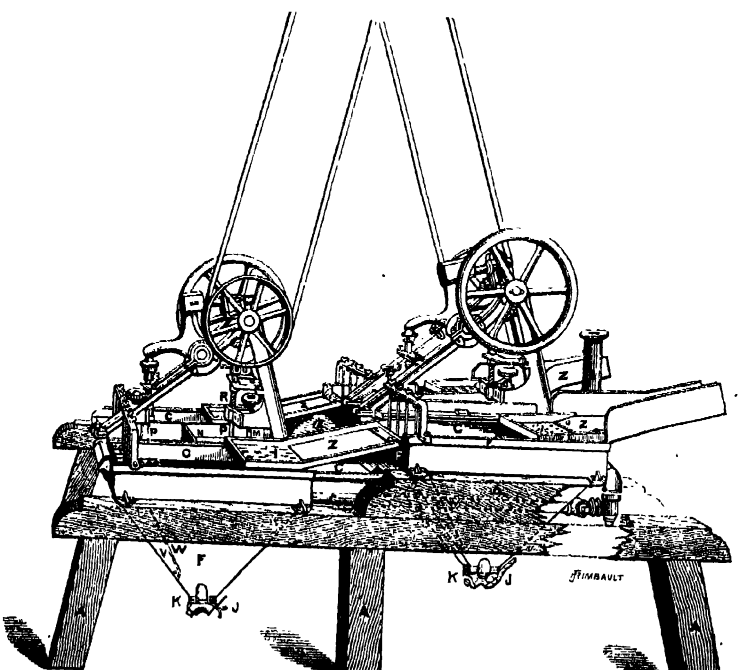

Fig. 215.

sieve itself is jerked up and down in water. The lighter particles are thus lifted and gradually carried off in the stream of water flowing over the sieve, leaving the heavier and richer stuff to settle gradually through the sieve into the hutch, from which it either passes off continuously through a regulating hole at bottom, K J, or is discharged at intervals if the supply of water is scarce. In order to prevent accumulation upon the sieves of stuff which may be too light to pass through the bedding, yet too heavy to be carried over the lips of the hutches by the overflowing stream of water, "ragging gear" is in some cases provided, consisting of a row of holes closed by taper plugs fitting into conical seatings; the height of the plugs is adjusted by thumb-screws, P, so as to regulate the area of the openings according to the

quantity of stuff to be got rid of, which never amounts to much; this falls into a compartment, V, and passes out through a hole at bottom. A second jigging-machine is fixed immediately in the front of the first, at a few inches lower level, by which the overflow from the first, by means of the shoot Z, is received, and jigged a second time in a similar manner.

Slime or Buddle Jigger.—This jigger is taking the place of the round buddle in various dressing works, the piston of which makes from 300 to 500 strokes per minute. The construction of the apparatus is shown in Fig. 216. The stuff is introduced to a circular distributing-table, S, by means of pipes, *b b*. From this distributing-table the slime falls into an annular launder, *r r*, from whence it drops through opening upon the head of an annular sieve. It is then jigged, the concentrated portion passes through the

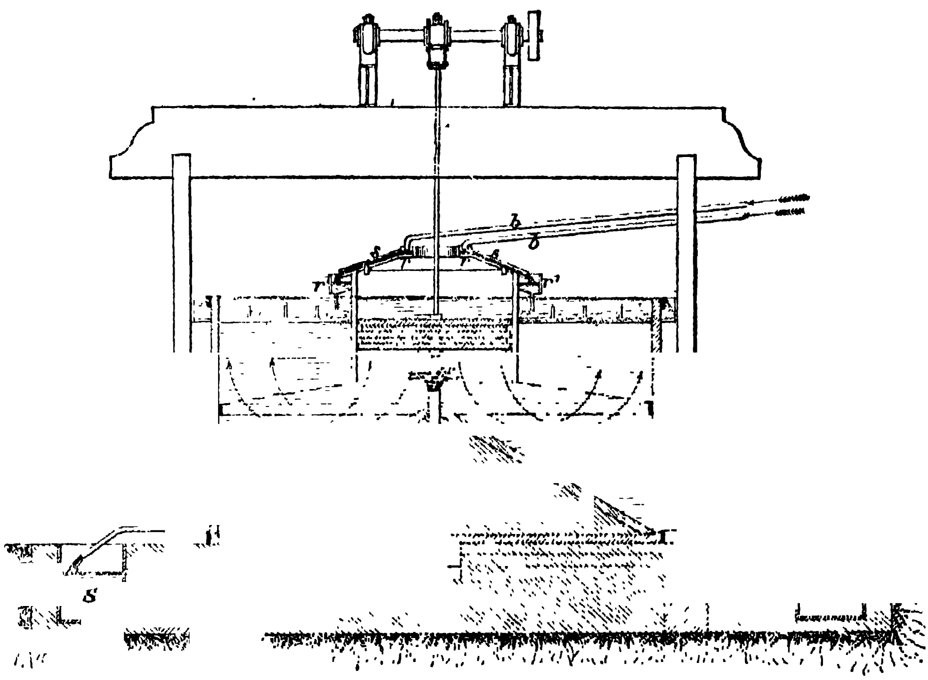

Fig. 216.

bed in the sieve into the cistern T T, while the waste flows from the outer edge of the sieve into an annular launder outside of the cistern. From the cistern T T the concentrated ore is discharged through gas piping into boxes S S. Clear water is supplied to the cistern T T immediately under the piston, and its flow, indicated by the arrows, is uniformly distributed to the bottom of the annular sieve. The holes in the copper sieve are 1½ millimetre diameter, while the bed on the sieve itself is composed of large grains of ore ½ inch diameter and 3½ inches thick. For slime scarcely of a "sandy feel" the piston-stroke should be about ½ inch, and the number of strokes not less than 300 per minute. The quantity of clear water requisite per minute is about 18 gallons. The slime sent to this buddle should be first classified into equivalents. The working capacity of a buddle jigger is nearly double that of a round buddle 25 feet diameter, while the waste from the former is

much poorer in metallic ore than that obtained from the latter apparatus. By arranging several of these jiggers one below the other, each of a lesser diameter, slimes consisting of sulphide of lead, blende, mundic, and vein stuff may be separated from each other and satisfactorily concentrated. The slime jigger illustrated has the following dimensions:—

Outside diameter of cistern, 9 feet; diameter of piston, 3 feet; height of cistern, 4 feet; fall of sieve, 4½ inches.

(G.) *Buddles and Tables.*—It has already been observed, in reference to continuous jigging machinery, that if two spheres of equal volume but of different densities drop together from the same height in a column of water, the heavier of the two will arrive at the bottom first. In this instance, the density of each of the spheres is only opposed by the resistance offered to its sectional area, viz. by the water through which the sphere is falling.

If, however, two spheres of different densities have an equal velocity of fall in water (equivalents), the diameter or sectional area of the lighter will be greater than that of the heavier sphere. Now if the two spheres be placed side by side on a perfectly flat table no movement will occur; but if a slight stream of water be applied to their surfaces, the one having the larger diameter or greater surface (the lighter sphere) will be impelled more rapidly and separate from the other (the heavier sphere), and if the table be slightly inclined, the rate of movement of these several spheres of different diameters will be accelerated. To these principles the separation on buddles or tables of metalliferous grains from gangue having an equivalent rate of fall in water must be referred.

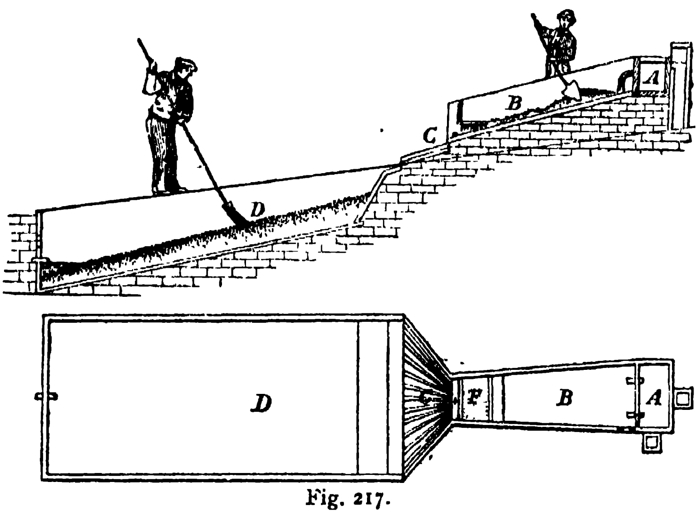

Fig. 217.

Hand Buddle.—This buddle usually consists of a wooden box, Fig. 217, D, about 8 feet in length, 3 feet wide, and from 2 to 2½ feet deep, sunk in the ground, and having an inclination of about 2 feet in its whole length. At the head of this box a distributing-board, C, is placed, which is in communication with the trough B, and a water launder A. The stuff is thrown into the trough B, when it is stirred by the buddler's assistant. The fine slime then passes through a perforated plate to the distributing-board C, and from thence in a thin and uniform stream into the buddle D, when the buddler carefully and continually sweeps the slime and water across the buddle and somewhat against the direction of the current, with the view of freeing the grains of tin from any viscid matter which may accompany them, and depositing them at the head of the buddle. In the tail-board at the lower end of the buddle is a vertical row of holes a few inches apart, through which the surplus

water flows, and which holes one after the other are stopped up with plugs as the stuff rises in the box. About 9 inches in length of water is kept between the stuff and tail-board, with the view of preventing the escape of any valuable stuff through the holes. Four-and-a-half buddlesful are generally finished by two boys in ten hours. The buddle when filled is arbitrarily divided perpendicularly into four parts—the "head," the "fore middle head," the "middle head," and the "tail." The head, which generally occupies about one-third of the buddle, is then re-buddled and divided into four parts as before, the head being tossed and thereby rendered fit for the smelting furnace.

The Knife or Impeller Buddle.—About the end of the year 1845 the agents of the Lisburne mines, Cardiganshire, invented a knife buddle which is fully described in "Records of Mining and Metallurgy," by Phillips and Darlington. This machine consisted of an inclined table and a reciprocatory frame carrying fifteen knives. The knife-frame made fifteen strokes per minute, and washed 40 tons of stuff per ten hours, which stuff yielded 12 tons of best, 4 tons of second class ore, and 24 tons of waste, which contained 2 per cent. of ore. Later, Captain Thomas Ball, connected with the Goginan lead mines, Cardiganshire, mounted the knives on a trommel frame, which is now known as the "Impeller Buddle." It consists of a cylindrical frame, 9½ feet long and 6 feet diameter over all, rotating on an horizontal axis, and carrying a series of scrapers or knife-blades arranged in spiral lines round its circumference, which revolve close to a cylindrical casing lined with sheet-iron, but without touching it. The casing forming the bottom of the buddle extends rather less than one quarter round the circumference of the revolving frame as shown in Fig. 218. The stuff is supplied at one end of the buddle from the hopper A, and is made to traverse gradually along the whole length to the other end, F, by the propelling action of the revolving knives, which are fixed obliquely and follow one another in spiral lines round the cylindrical frame. A gentle stream of clear water from the launder D flows down over the whole curved surface of the bottom of the buddle, and the minerals are gradually propelled to the farther end, where they drop over the edge into

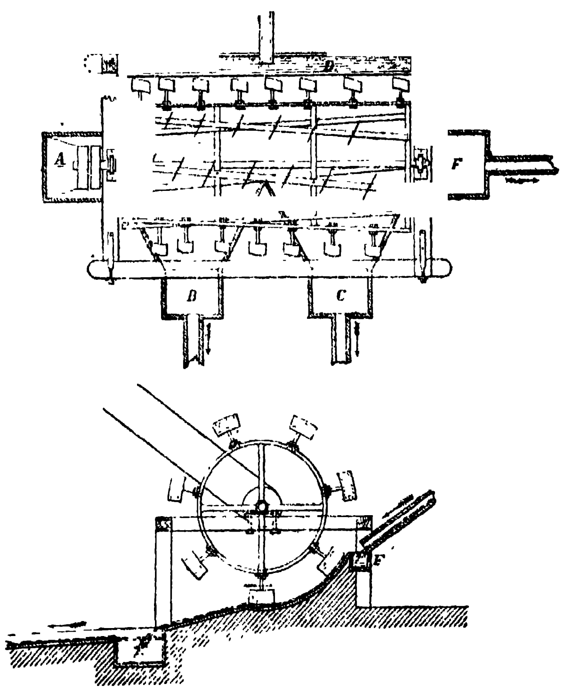

Fig. 218.

the receptacle F. The machine is driven at about 20 revolutions a minute, giving the knife-blades a speed of about 370 feet a minute. The action of this machine is found to be very perfect, the whole of the stuff being continually turned over by the knife-blades and pushed upwards against the descending stream of water, which washes out the lighter particles; the result is an unusually complete separation of coarse-grained tin ore in a single operation with only a small proportion of loss in the waste. The contents of the second waste hutch, C, are so poor as not to pay for any further dressing, while the waste in the first hutch, B, containing a small proportion of slime tin, is passed through the buddle a second time.

The quantity of stuff treated at the Lisburne mines, by a single machine, was 2¼ tons per hour; the stuff buddled contained about 15 per cent. of lead, and was concentrated to afford 50 per cent. of that metal. By repeating the concentration the 50 per cent. stuff was raised to afford 75 per cent. of metallic lead. The stuff dressed included quartz, blende, carbonate of lime, Clay-Slate, and lead ore.

This form of buddle may be regarded as a valuable concentrator of heavy ore, associated with a light gangue such as galena and carbonate of

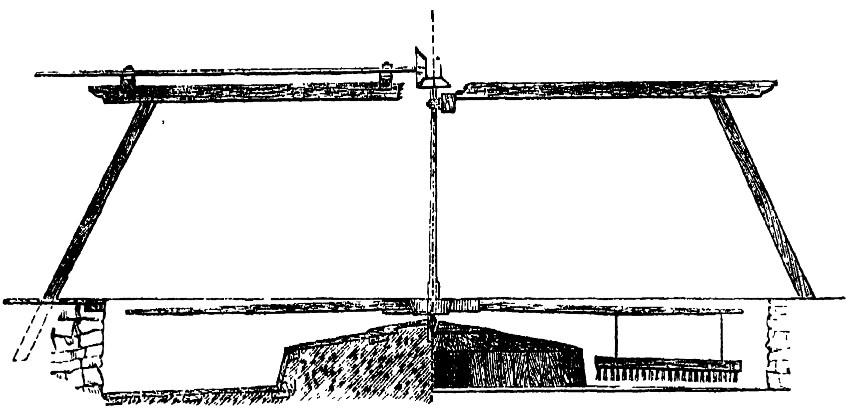

Fig. 219.

lime, or of coarse-grained oxide of tin mixed with fine-grained quartzose sand.

Centre-head Buddle.—This buddle, Fig. 219, known as the convex or centre-head buddle, is about 22 feet diameter, and from 1 to 1½ foot deep at the circumference, with a raised centre 10 feet diameter, and a floor falling towards the outer circle at a slope of about 1 in 30 for a length of 6 feet. The stuff is brought to the centre of the buddle in launders, into which a constant stream of water flows; and it is distributed upon the raised centre from a revolving pan shown in plan, Fig. 221, carrying a number of spouts, so as to spread the liquid stream very uniformly in a thin film, which flows gradually outwards over the sloping floor to the circumference, Figs. 220 and 221. In its passage down the slope the material held in suspension by the water is gradually deposited according to its specific gravity, and the ore being the heaviest is the first thrown down, and is consequently in greatest proportion towards the centre of the buddle. The outflow for the waste and slime from

the circumference of the buddle is regulated by a wooden partition perforated with horizontal rows of holes, which are successively plugged up from the bottom as the height of the deposit in the buddle rises. To facilitate the uniform spreading of the stuff over the floor of the buddle, and prevent the formation of gutters or channels in the deposit, rollers attached to arms are employed, from each of which is suspended a sweep consisting of a brush or small piece of cloth, which being drawn over the surface of the deposit keep it to an even surface throughout. The distributing spouts and sweeps are driven at about 5 or 6 revolutions per minute.

As the deposit accumulates in the buddle, the sweeps are successively

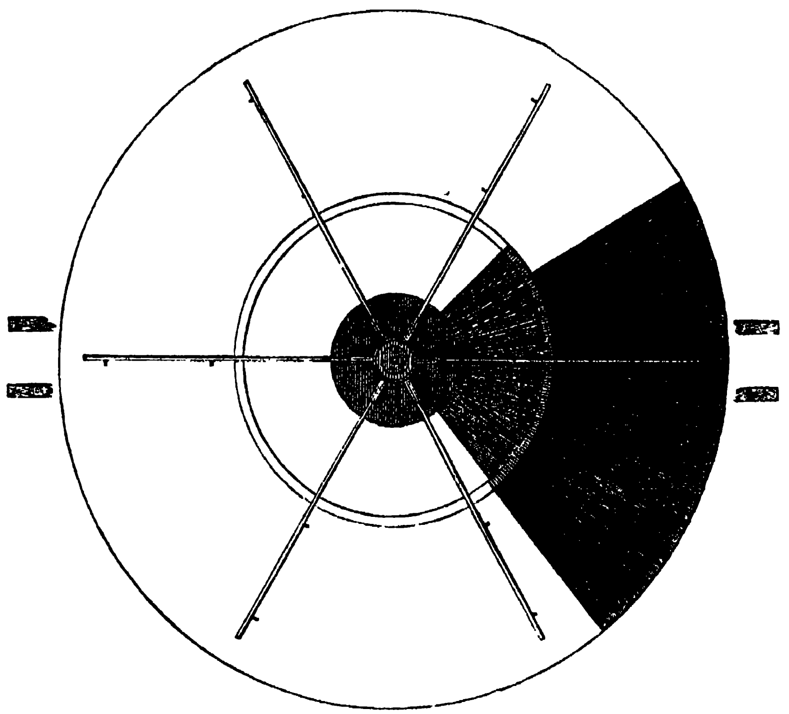

Fig. 220.

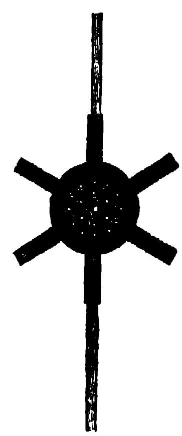

Fig. 221.

raised to a corresponding extent, and the process is thus continued until the whole buddle is filled to the top of the centre cone, which usually takes about ten hours. The contents are then divided into three concentric portions, each about a third of the whole breadth, called the head, middle, and tail.

In tin dressing, the head or portion nearest the centre contains about 70 per cent. of all the tin in the stuff supplied to the buddle, the middle some 20 per cent., while the tail or portion next the circumference contains only traces of oxide of tin.

Concave Buddle.—The Heads from several round buddles are usually thrown into a trough or launder, into which a stream of clear water flows of sufficient volume to convey the stuff to concave buddles. Fig. 222 shows Borlase's concave buddle in elevation and plan with a mechanical arrangement for adjusting the level of the central outflow by using a ring H that slides upon the centre vertical shaft. By this means the height of the

outflow is adjusted more gradually and uniformly than by the plugged holes in the ordinary buddles, and there is less liability to waste by guttering; the sliding-ring H is raised by hand by the rod and lever L, provided with adjusting fly-nuts N, and the arms of the sweeps D, being supported upon the rising ring, are kept at the proper height by the same adjustment; the stuff is introduced into the box M, and prepared for the buddle by means of the revolving agitator; it then passes through a perforated plate N, down the launder to a central box, from whence it is distributed to a circular ledge of the buddle by six revolving spouts, P, from which it flows uniformly over the conical floor, falling at a slope of about 1 in 12, towards the centre H. The greatest proportion of the ore is deposited round the circumference of the floor, while the slime and waste flow over the top of the rising ring into the well H.

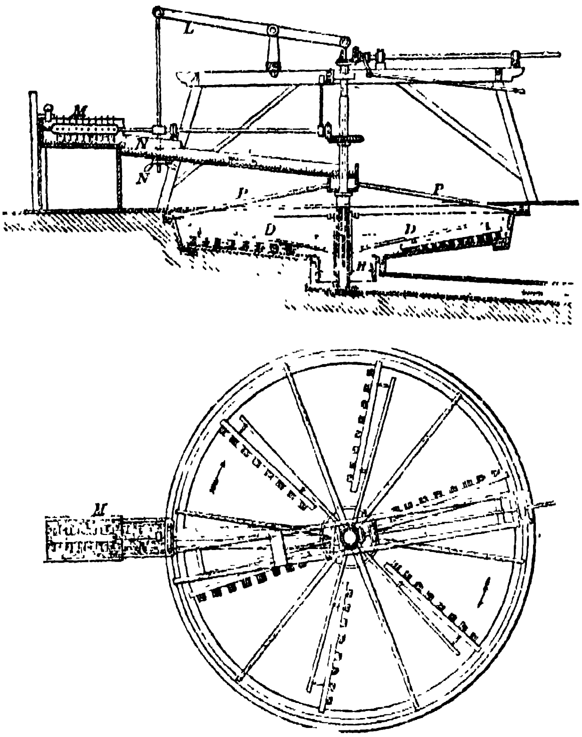

Fig. 222.

Ring Buddle.—Although the bottom or table part of a centre-head buddle is uniformly laid at a given angle, yet as soon as the enrichment of the stuff occurs, this angle in the stuff itself often increases to a material and unsatisfactory extent, especially if the stuff happens to be largely composed of heavy ore and a light waste.

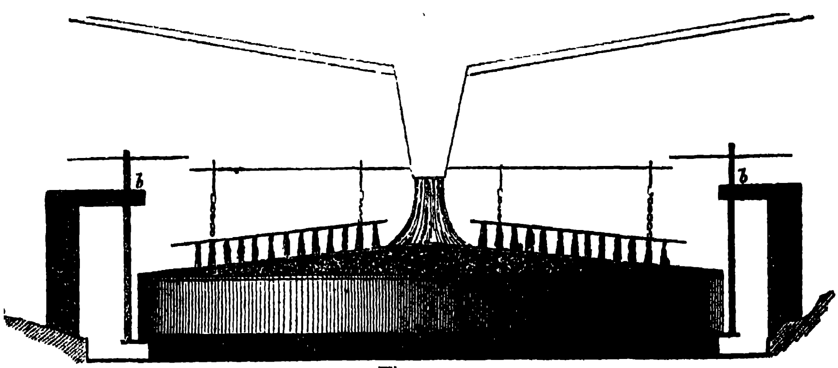

Fig. 223.

To neutralise this drawback a movable ring is sometimes placed outside the table of a centre-head buddle. Fig. 223 shows a ring applied to a centre-

head buddle—*a*, ring; *b b*, side screws for raising or lowering the ring as may be required.

Borlase's inclined buddle consists of a slowly revolving annular table, 24 feet diameter and 6 feet wide, placed at an inclination at 1 in 12 from an horizontal line (Fig. 224). A is the table or frame, which is fed from the distributors C C C, with the ore to be treated, which is brought through the launder B. As the ore falls on the table it is acted on by a gentle stream of clean water from D, which washes off the matrix and earthy matter, the richer tin remaining on the outer periphery, the poorer on the inner, and the waste flowing from the inside of the circular frame at E E E. As the table revolves, making one turn in three minutes, and the lower side is attained, the ore on it is washed off by jets of water from the pipes H H, the richer, or crop, into launder F, the poorer into G, from whence each is conveyed away through the launders I and K respectively. The constantly varying inclination of the table, which at the receiving side runs from the circumference to the centre, and at the washing-off side from the centre to the circumference, enables the workman to wash off the cleansed material at any point desirable. This point is found by experiment to be within 21 inches from the edge.

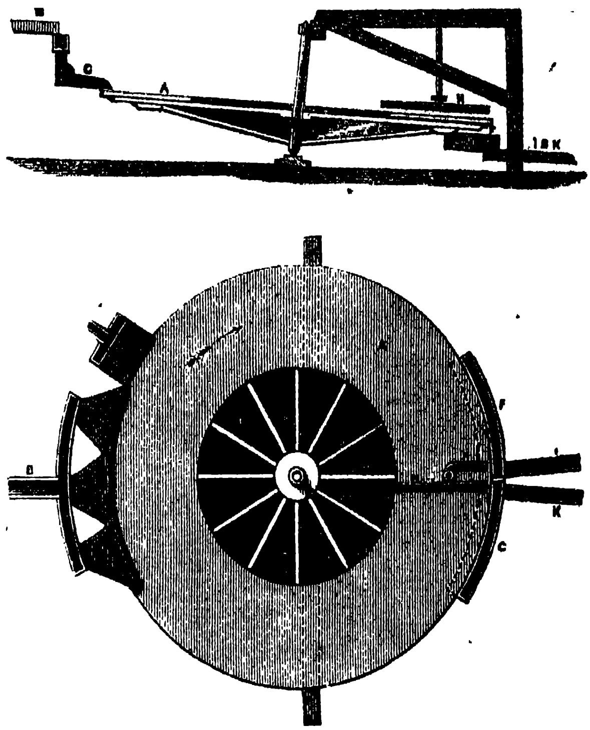

Fig. 224.

The advantages claimed for this machine are its great simplicity, the saving of nine-tenths of the ore at the first washing, and the saving of much labour of dressing, while the waste will not pay for retreatment.

Dead Frame.—In Fig. 225 is shown a self-acting "ragging" dead frame used on the Red River, Redruth. The bed of this table, 6 feet long and 6 feet wide, is set at a grade of 1½ inch to the running foot. The slimes are delivered to the table by means of a head board, and in passing over its surface a portion of the tin ore present is deposited, which is washed every few minutes into a launder, set at the foot of the table by the canting or falling over of the V launder set at the head of the table, which launder is filled with water.

It will be observed that the canting V launder is connected by means of a long arm, with a lap shown in the figure covering the tin stuff launder

set at the foot of the table. This lap is opened by the rotating fall of the V launder, and is almost immediately closed by the return of this V launder to its normal position. The time of filling the V launder is governed by the diameter of the hole in the water launder, fixed just above the former. In the fine slime tin dressing in operation on the Red River two other frames are employed differing in their dimensions. In the "second or doubling

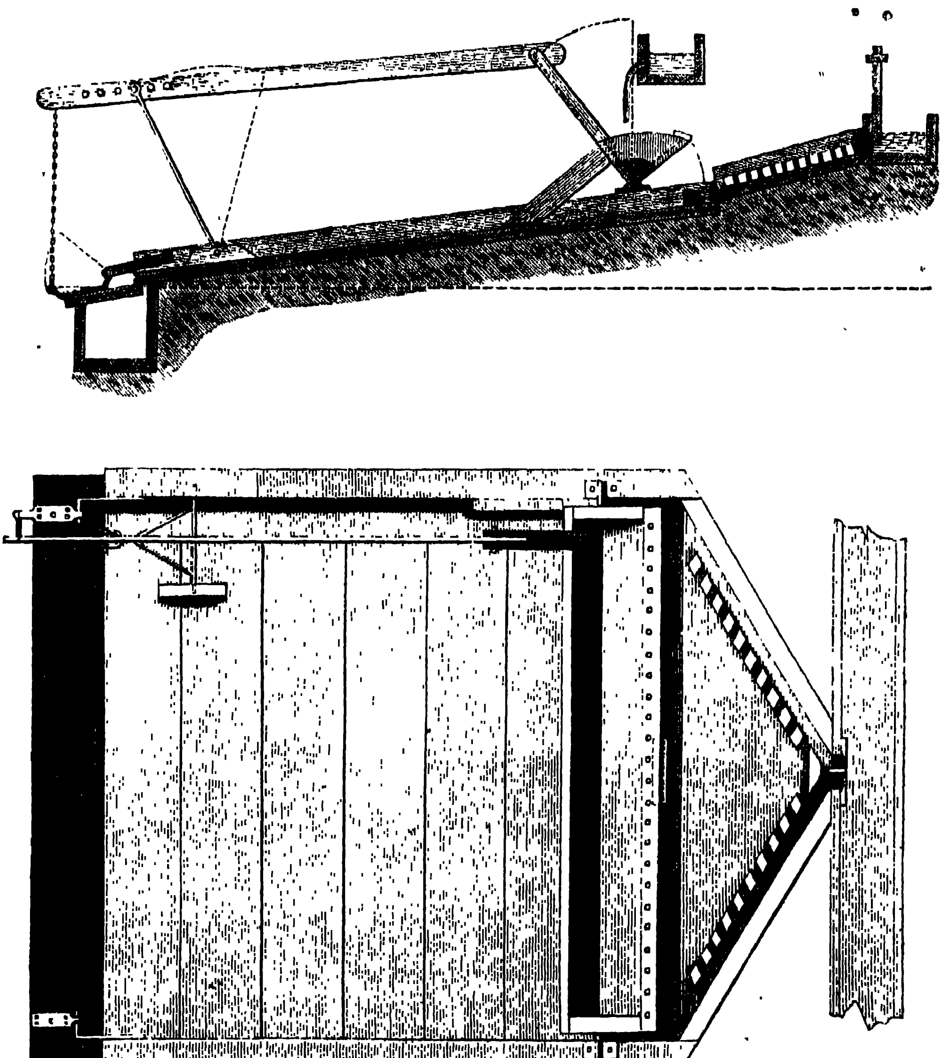

Fig. 225.

frame" the bed is 8 feet long, 6 feet wide, with a grade of 2 inches in a lineal foot. This frame, instead of being automatic, is worked by hand. It is also fitted with two launders at the head for delivering to the table clear or slime water as may be required. The "cleaning frame" differs from the second frame in the following details.

Instead of one bed 8′ 0″ × 6′ 0″ there are two beds each 6′ 0″ square separated by a launder and lap, so that the stuff, after being treated on the

first or uppermost bed, runs over the lap on to the second bed; hence the total length is 12′ 0″ exclusive of the lap.

The following particulars relate to the dead frames formerly in use at Great Wheal Vor. Number of heads of stamps in operation, 48; proportion of stuff for dead frame obtained from 48 tons of stuff stamped, about 15 tons; number of ragging frame, 40; number of doubling frames required to treat concentrates from 40 ragging frames, 28; number of trebling frames to treat concentrates from 28 doubling frames, 4; labour required, one girl to 14 frames, or from five to six girls for the whole series of frames, also one boy shovelling stuff to supply the 28 doubling frames. The frames were made of American deal plank, $1\frac{1}{2}$ inch. The faces of the frames were cleaned when in work with a hempen swab once a week. The fall of the ragging frame was $1\frac{3}{4}$ inch to a lineal foot. The diameter of the hole, which was lined with an iron thimble for admitting water to head board of table, was $\frac{3}{4}$ of an inch. The diameter of hole for delivering water to V-shaped launder or washing-trough, $\frac{3}{8}$ inch.

Brunton's Concentrator.—This apparatus is well adapted for effecting the concentration of fine slime ore. The following particulars relate to tables for the enrichment of lead slimes:—

Length of table	16 feet.
Width	6 ,,
Speed of cloth	3 revolutions per minute.
Length of blow given to table	$1\frac{1}{4}$—$1\frac{1}{2}$ inch.
Number of strokes	75 per minute.
Quantity of water required	12 gallons per minute on the average; the richer the stuff, the less water required.
Quantity of stuff worked per 12 hours per table	200 cubic feet.
Richness of stuff	4 per cent. of lead on the average.
Percentage of concentrates obtained	40 cubic feet per 12 hours.
Number of hands required	5 boys to 2 tables.
Number of revolutions of feed apparatus	9 per minute.
Angle or fall of table	9 inches in 16 feet; the richer the stuff, the more inclined must be the table.
Number of revolutions of feed apparatus per minute	
Number of holes per square inch in stamps grate, through which stuff is passed for concentration on table	72 holes in a square inch.

Ore enriched from 4 to 10 per cent. by passing once over the table. One millimetre is the average size of the stuff treated on these tables.

(H.) *Calciners.*—For the purpose of getting rid of arsenic, sulphur, and other volatile impurities sometimes associated with oxide of tin and altering the relative densities of these minerals, calcination is resorted to. This operation is in some mines effected by means of an ordinary reverberatory furnace, in others by the well-known Brunton revolving furnace, or by the rotary furnace devised by Robert Oxland, of Plymouth, and the late John Hocking, of Redruth. Brunton's, the older mechanical furnace, is illustrated in Taylor's "Records of Mining," published in 1829. This furnace consists of an horizontal revolving table about 12 feet diameter, and of a circular shell and dome. The table, slightly conical, slopes from the centre downwards to the circumference. The tin stuff, delivered to the centre of the table through a hopper, is exposed to a flame passing through the furnace, and is continually stirred by a set of stirrers fixed in the dome, while the table makes from 4 to 6

revolutions per hour. The stirrers are set obliquely to the line of rotation, and gradually shift the stuff from the centre to the circumference of the table, when it falls into a chamber beneath.

Fig. 226 shows Oxland and Hocking's calciner as adopted at several mines in Cornwall. It consists of a long wrought-iron cylinder, A, lined with firebrick, 3 feet inside diameter and 32 feet long, placed at an inclination of 1 in 16 to 1 in 24, according to the nature of the stuff to be treated, and supported upon carrier wheels, upon which it revolves, making 6 to 8 revolutions per hour. The tin stuff or "whits" supplied to the higher end of the cylinder through a hopper fitted with a feeding screw, B, gradually traverses the length of the cylinder to the lower end, when the stuff falls into a chamber, D, from which it is removed for further treatment. The heating furnace, C, opens into the lower end of the cylinder, and the volatilised arsenic and sulphur, &c., are carried off by a flue, F, from the upper end; this flue is extended to a considerable distance and divided by baffle walls into a succession of chambers, in which the arsenic is deposited and periodically

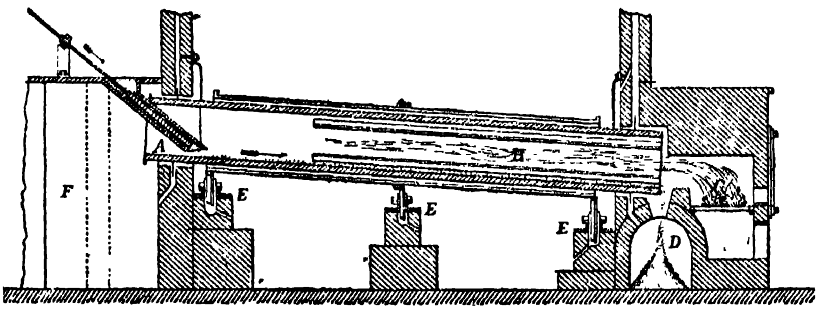

Fig. 226.

collected. The time taken for the stuff to pass through the calciner is from 3 to 6 hours. The firebrick lining of the calciner is constructed with 4 longitudinal ribs, H, projecting internally as in a mortar mill, and extending two-thirds of the length from the lower end. In the revolution of the calciner these ribs have the effect of continuously shifting the stuff and exposing the whole of it to the heat. In this calciner the stuff, being supplied at the upper end farthest from the heating furnace, is exposed first to the lowest heat and afterwards to a gradually increasing heat as it works its way along to the hotter end of the calciner; by this means the most advantageous effect is obtained from the fuel consumed in the furnace.

At Wheal Basset the calcining cylinder, 28 feet long and 4 feet diameter, is set inclined towards the fireplace at 1 in 16. The cylinder makes 4 revolutions per hour, and calcines 7 tons of whits in 24 hours, with a consumption of from 17 to 18 cwts. of coal. The labour charges amount to £7 per month. Once in six years the cylinder requires to be relined with firebrick.

At Wheal Polrose the whits consisted of oxide of tin, iron, and copper pyrites. The diameter of the bed of a Brunton's calciner was 12 feet; number of revolutions per hour, 5; weight of tin whits calcined per day of 24 hours, 6 to 7 tons; depth of tin whits, 3 to 4 inches; reduction in weight of tin whits after roasting, 10 per cent.; number of tons of roasted tin whits

required to make 1 ton of black tin, three; weight of coal consumed per ton of whits, 56 lbs. The calciner was driven by means of a water-wheel 5 feet diameter and 12 inches wide. A pinion 9 inches diameter on the water-wheel shaft was geared into a spur-wheel 33 inches diameter.

Various calciners would probably be found efficient for the calcination of tin-whits, such as the Hasenclever, Gerstenhofer, Livermore, and the O'Hara furnace.

(J.) *Humid Processes.*—The process of extracting "vitriall or coppris" from burnt ores was evidently practised in this country by the Germans in the time of Elizabeth. In 1582 an offer was made to Sir Francis Walsingham, Knight, by one Joachim Gaunse, for "making of copper vitriall and coppris and smelting of copper and leade ures." In article 5 it is stated: "After copper ure be roasted and redie to smelting (w'ch roste is done in one fire) then must the vitrall or coppris, or w'ch of them shal be thought moste mete, be taken from the ure before it come to the smeltinge, first w'ch is done by letting water passe through the ures, of w'ch water the coppris or vitriall must be made, and that water doth not onely drawe the vitriall and coppris from the ure, but also divers other hurtfull humours being by nature enemyes to the copper, as arsenick, sulphur, antimony, allome, and ironn." From a letter inserted in the Philosophical Transactions for 1752, it is stated that the existence of copper, in solution in the water from Ballymurtagh, Wicklow, had only lately been discovered by accident, but had given rise to extensive apparatus where 500 tons of iron were at the same time employed to effect the precipitation of the costlier metal. The mode of operating was very rude: pits were dug 10 feet long, 4 feet wide, and 8 feet deep, floored with flags and lined with stones, and the iron bars were laid on rough wooden beams fixed across from wall to wall. By this mode a ton of the precipitant obtained from the pits yielded 16 cwts. of the finest copper.

Pryce, in his "Mineralogia Cornubiensis," page 33, observes: "Dr. Rouby, a curious foreigner, set on foot a manufactory of Roman, or blue, vitriol at Treleigh, in Redruth, about five-and-twenty years since (1753), which dropped, only with a loss of £90, by means of some disputes and disagreements among the persons concerned. It was collected from the waters which were left from the lotions of black tin after it had been calcined in the burning house for the discharge of its mundick. The water being strongly impregnated with vitriolic particles after it had been decanted clear from its dregs, was kept constantly boiling by a gentle fire for seven or eight days in a leaden boiler, which being evaporated to a pellicle, it was drawn off and set to crystallise in proper vessels. The time for crystallization was generally three to five days, according to the different degrees of the impregnation of the water, 8 tons of which well saturated with vitriolick particles would yield a ton of blue vitriol."

Towards the close of the last century, copper was obtained at Cronebane and Tigrony, by means similar to those employed at Ballymurtagh in 1752, only it was usual to add to the strength of the solution by placing in the water a quantity of poor pyritic ore which had undergone a process of roasting. The ratio of pure copper to the precipitate powder was only about 6½ cwts. to the ton.

On the 31st of May, 1838, Duclos patented improvements in the manufacture of zinc, copper, and antimony, in which he claimed the mode of manufacturing copper from copper ores by repeated oxidation of the sulphurets and dissolution of the sulphates therefrom, precipitating the metallic copper by iron and the concentration by heat of water containing copper.

On the 10th of June, 1843, he also obtained a patent for improvements in the manufacture of lead, tin, tungsten, copper, and zinc.

As oxide of tin (black tin) is almost indifferent to the action of acids, the treatment of tin stuff for the separation of other metallic oxides is comparatively easy. With moderate care, mine tin might be made equal in quality to stream tin for the production of metal. Considerable money advantage would therefore accrue to certain tin mines if the black tin were rendered pure.

In 1842, at the Balleswidden mine, Cornwall, acids were employed by Duclos in the treatment of tin ore. In the same year, October 20th, 1842, a patent was obtained by W. Longmaid, having for its object the utilization of the sulphur in sulphur ores by mixing with them common salt and roasting the mixture, converting the sulphur into sulphate of soda, the copper into a soluble chloride, washing out both, leaving oxide of iron, tin, and earthy matter, from which the oxide of tin could be mechanically separated. Longmaid's process in the main was subsequently adopted by Henderson, and is essentially the one in use by the copper extractors at Widnes and elsewhere.

When the foreign matter consists almost exclusively of oxide of iron muriatic acid may be advantageously employed, or when the stuff after calcination contains copper, dilute sulphuric acid may be used as the solvent, the sulphate of copper washed out, and the copper precipitated in the metallic state with iron or as an oxide with soda ash. About the year 1844 Robert Oxland, of Plymouth, successfully introduced at Drake Walls his process for treating tin stuff associated with wolfram.

At East Pool, near Redruth, some portions of the tinstone contains a considerable quantity of wolfram. The tinstone is reduced and dressed in the ordinary way, calcined to get rid of arsenic and sulphur, subsequently buddled and tossed, and then mixed with soda ash in the proportion of 50 per cent. of the quantity of wolfram present, and placed in a heating furnace. The whole is then subjected to a great heat in a furnace for about four hours, occasionally stirred to decompose the wolfram and to form tungstate of soda, when the charge is drawn and thrown into a lixiviating tank. The solution of soda is drawn off from these tanks into evaporating pans until dry tungstate of soda is obtained, and in turn tungstic acid, by treating tungstate of soda with hydrochloric acid. The oxide of iron and manganese being insoluble are readily separated in the subsequent process of dressing the lixiviated stuff. In the furnace the stuff sometimes bakes into hard masses, which must be broken up, crushed or pulverised, and be redressed before preparing it for market.

About the year 1857 the late W. Henderson employed at Alderley Edge, in Cheshire, hydrochloric acid for the purpose of extracting blue and green

carbonates of copper from a Sandstone found in that district. The apparatus consisted of a series of small stone tanks, each 11 feet long, 8 feet wide, and 4 feet deep, fitted with a false bottom. Pumps for lifting the acid from beneath the false bottom of one tank to the top of the next were employed in order that the whole solvent power of the acid might be utilised, and a series of ordinary vats were used for precipitating the copper. In eight years, ending 1872, 95,000 tons of cupreous Sandstone treated at Alderley Edge by dilute hydrochloric acid afforded 1,444 tons of fine copper, or 1½ unit of copper per ton of Sandstone treated.

In 1875 a process was introduced by Mr. Fred. J. King for obtaining copper and zinc from the poor carbonate and oxide of these metals by means of the solvent power of ammonia or carbonate of ammonia, the ammonia being recovered and used for a fresh attack. The operation was conducted in close vessels of simple construction, and the ammonia recovered from the solution after it had done its work by means of heat applied to the outside of a vessel and an exhaust-pump put in connection with the inside, while the metals were precipitated as an oxide or carbonate of copper. Some carbonate of copper treated by King's process, affording 3½ per cent. of metal, yielded an oxide which contained 79 per cent. of copper.

Extracting Copper from Burnt Cupreous Pyrites.—About 700,000 tons of cupreous pyrites, containing 3 to 3½ per cent. of copper and 46 units of sulphur per ton, are annually imported into this country chiefly from Spain and Portugal. The sulphur is "burnt" for the production of sulphuric acid, and the residue is roasted with salt for the purpose of converting the copper present into a chloride. The following is a brief summary of the process. (1.) The burnt ore, containing on an average 2½ to 3 per cent. of sulphur, is ground between rolls. (2.) A sufficient quantity of unburnt sulphur is added to the ore to raise the percentage of sulphur to an amount slightly in excess of the copper present, at the same time a sufficient quantity of salt is added to convert the copper into a chloride. (3.) The mixture is passed through a sieve six holes to the lineal inch and then into a roasting furnace having flues beneath the bed through which the flame passes before coming into contact with the ore. (4.) The mixture, about three tons charged into the furnace through a hopper in the arch and spread evenly over the bed to a depth of 4 to 5 inches, is stirred and rabbled from time to time in order to expose fresh surfaces to oxidation, the temperature not being allowed to exceed dull redness. (5.) Hydrochloric acid evolved during the roasting is conveyed to a condenser from which a weak solution is obtained, and subsequently employed in the lixiviation of the roasted ore. (6.) From 6 to 6½ hours are necessary for converting the whole of the copper in the ore into a soluble chloride, when the charge drawn out on to the floor of the furnace-house is allowed to cool considerably, and then taken to wooden lixiviating tanks holding 16 tons each fitted with false bottoms, upon which is a layer of cinder serving as a filter. (7.) The hot chloridised ore is washed with hot water and finally with a little hydrochloric acid; the first or stronger solutions are then ready for precipitation by means of metallic iron, the weaker are run into separate tanks, from whence they are pumped back to serve as washing water for a fresh lot of furnaced ore. (8.) The copper present in the

strong solution is precipitated by means of cast or wrought iron immersed in the solution itself, and if the solution be kept to a boiling-point by means of steam the precipitation will be completed in about twelve hours. (9.) The spent liquor, chloride of iron, which is valueless, is syphoned off from the precipitated copper, and the latter, freed from iron by washing through a perforated plate, contains when drained and dried from 70 to 75 per cent. of metal ready for the smelter.

Claudet's Silver Process.—On January 31, 1870, Claudet patented a process entitled, "Improvements in the Treatment of Cupreous Ores containing Silver." In many copper-extracting works the silver present in the cupreous solution, previous to the precipitation of the copper, is extracted by mixing with the solution a quantity of soluble iodide, usually that of potassium, sufficient to combine with the silver present. The insoluble iodide of silver is allowed to subside and the copper solution drawn off into the precipitating tank. After a considerable quantity of iodide of silver has been collected, it is well washed to free it from copper, and whilst suspended in water metallic zinc in thin slips is added and the whole kept boiling by a jet of steam. The iodide of silver is then decomposed, when metallic silver and iodide of zinc are produced. The latter solution serves to precipitate a fresh quantity of silver, while the former when dried is ready for the bullion smelter.

At the present time cupreous mine-water is usually led through a series of narrow launders slightly inclined and interrupted at intervals by deep hutches. The iron placed in the launders is frequently swept with a broom for the purpose of removing the precipitate and obtaining fresh surfaces of iron for the deposition of the copper. With cupreous water (CuO, SO_3) and iron as a precipitant the following chemical action takes place.

CuO, SO_3. $\qquad\qquad\qquad\qquad$ FeO, SO_3.

Fe $\qquad\qquad\qquad\qquad\qquad$ Cu

Sulphate of iron (FeO, SO_3) becomes oxidised by exposure to the air and falls to the bottom as ochre (Fe_2, O_2). To avoid the expense of brushing the iron deposited in the launders, Captain Isaac Richards devised a sprinkler, a kind of round buddle, in which he placed scrap iron. The arms of the buddle, perforated with fine holes, were connected with a tank annular with the central axis. On filling this tank with cupreous water, it flowed to the arms, issued through the holes, caused the arms to revolve, and thereby sprinkled the iron with the liquor, keeping the iron clean in the operation. The deposit obtained by this method was for every 3 tons of iron converted into a sulphate 2 tons of copper precipitate, containing 50 per cent. of pure copper. In other words, 300 units of iron precipitated 100 units of pure copper.

The ores best fitted for the humid process are poor oxidised ores associated with silicious substances, which can only be smelted at a considerable consumption of fuel, and which would also suffer great loss of metal in the

dressing. It is of essential importance that the ores wash well, and do not contain substances soluble in acids, such as lime or sparry iron ore, and therefore oxidised ores with insoluble gangue are treated with the greatest advantages.

(K.) *Separation of Magnetic Iron Ore.*—In some of our metalliferous mines ores of two or three distinct kinds are produced from the same lode, which it is the business of the dresser to separate. When the specific gravity of each varies considerably the operation is not attended with much difficulty, but where an ore as blende is associated with spathose iron, iron pyrites, or copper pyrites—ores of almost similar specific gravity—a perfect separation is impossible by hydraulic means, and such ores are frequently unsaleable either from their low percentage of metal, the alloys they produce, or from the deteriorating effects consequent on smelting one ore with the other. The latter is especially the case when iron and copper pyrites occur with blende, the smelter obtaining a hard spelter.

Mr. F. J. King had his attention directed to this subject in a mine where the ores from the vein stuff consisted of lead, blende, and spathose iron. The lead was dressed without much difficulty, but owing to the almost similar specific gravity of the blende and iron these could not be separated, although the best known methods of sizing and mechanical dressing were resorted to. This is not surprising when it is known that the specific gravity of blende is about 4·0 and that of spathic iron 3·85. The blende raised from this mine being in quantity about three times as much as the lead, it became essential that the blende should be made marketable. In carrying out various experiments upon these ores, it was found that the iron, composed of protoxide of iron and carbonic acid (FeO, CO_2), would at a dull red heat part with its carbonic acid and become a magnetic oxide of iron. In practice it is necessary that this heating be done without access of air, or a higher oxide, which is non-magnetic, will be produced.

The treatment adopted is as follows:—

The blende and iron ores fed through a hopper into revolving iron retorts, heated by a fire beneath, are delivered, when heated to redness, into a close chamber. The ores thus prepared are carried by an elevator to the magnetic machine, which consists of four magnetic wheels, the magnets being so arranged that the whole surface of the wheel is magnetic. The ore falls upon a band which passes round the wheel. This band is made of any thin material which allows the magnetic force to pass through it, and the blende, not being held to the wheel, falls into a shoot and is received into waggons, while the iron adheres to the wheel and drops into another shoot at a point where the band is removed from contact with the wheel by means of a roller.

In the separation of copper or iron pyrites from blende, the treatment is somewhat similar, but the heating process is more simple, as access of air during the heating is an advantage. The result of heating pyrites is to remove a portion of the sulphur, bringing it to the condition of magnetic pyrites, which occurs as a distinct ore in some mines. Its composition is represented by $FeS_2 + 6\,FeS$, while that of iron pyrites before heating is FeS_2.

Instead of employing a wheel fitted with permanent magnets, electro-magnetic wheels may be successfully used. By calcining the ore in an ordinary flat bottom reverberatory furnace at a temperature of about 1250° Fah., and subsequently allowing it to pass over a couple of electro-magnetic machines, a good separation of blende from the magnetic oxide of iron may be effected. A Gramme machine will be found satisfactory for the purpose of generating the necessary magnetic current.

(L.) *Tossing and Packing.*—When most of the foreign matter has been separated from the tin stuff by successive buddling operations, the tin stuff is then subject to the process called tossing and packing, which has for its object getting rid of the finer particles of waste present. The tin stuff is put into a "kieve" about 3½ feet diameter and 2½ feet deep, and with an equal volume of water is continually stirred with a shovel in one direction until the tin stuff is in a state of suspended motion. After tossing or stirring the tin stuff undergoes the process called "packing," which consists in tapping the side of the kieve with a heavy iron bar for a period varying from a quarter of an hour to an hour; the bar is held vertically with one end resting on the ground, and with the upper end repeated blows of about 100 per minute are struck by hand against the edge of the kieve. This packing keeps up a constant gentle vibration among the descending particles and facilitates the separation of the tin ore, which gradually settles to the bottom of the kieve. Instead of a hand-worked, a mechanical hammer is employed at some mines for performing the packing, with the advantage of maintaining complete regularity in striking the blows for any length of time required. When the packing is finished, the upper portion of the stuff in the kieve is skimmed off and rebuddled, and the remainder, now called "whits," is taken

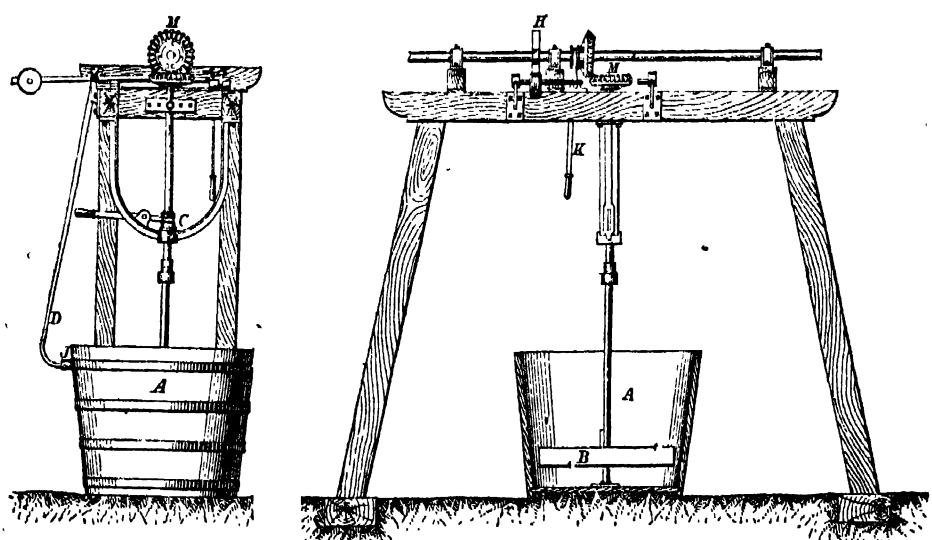

Fig. 227.

to the burning-house to be calcined. The kieve is completely cleared out before commencing with a fresh charge.

Fig. 227 shows a tossing, and packing or dolling machine: A, kieve;

B, dolly; C, clutch for throwing dolly in or out of gear; D, packing hammer; H, cam for lifting lever weight and packing hammer; J, head of packing hammer; K, lever for throwing packing hammer out of gear; L, shaft for running dolly and packing hammer; M, bevel wheels. The diameter of the kieve at the bottom is 34 inches, at top 42 inches, and depth 30 inches.

(M.) *Sampling Ores.*—The following description of sampling copper ore in Cornwall in 1778 is taken from Pryce's "Mineralogia Cornubiensis": "A dressed parcel of ore before the day of sampling is very well mixed by several men, who turn it over again and again, a person standing on the top of the pile or parcel, who spreads every shovelful circularly and as equally as he possibly can, so that in fact it is mixed with great exactness. This parcel, if less than ten tons, is divided into three doles or piles, if above ten into four doles or piles, and if ever so many more than nineteen tons it is divided into six doles, and then it is ultimately ready to be sampled. Now, when the samplers meet upon the spot according to appointment, either of them indifferently fixes upon the one-sixth, one-fourth, or one-third dole of a parcel, according as it is great or small, to take their samplers from. The miners then cut or part that dole athwart and across down to the ground, so that it is divided nearly into quarters by these transverse channels which are cut through it. Then a sampler with a shovel pares down a little of the ore from all parts of the channels to take as equal and regular a sample throughout the whole as he can, to the amount of two or three hundredweight, which is carried to a clean floor or laid on boards, and then well and regularly mixed in a small heap by itself. Next a sampler cuts this also into quarters, ordering any two of the opposite or adverse quarters to be returned to the great dole from whence they were brought. The remaining half he still mixes and quarters until it is brought to a small compass or quantity, when it is sifted through a small coarse wire sieve, and the large stones which cannot pass through the sieve are broken with a sledge or flat-polled hammer till all will pass through the meshes. After this he mixes it very curiously three or four times over, and so quarters and remixes it as before until it is reduced to a small quantity. Lastly, he puts about a pound or two of it in a small bag, which is a sample of the whole parcel. Each of his brother-samplers fills his bag likewise in order to assay or prove its value by fire."

This description of the method of sampling copper ore still remains correct. Unfortunately, the limited quantity of ore raised has dispensed with the necessity for monthly sales. The ticketing sales now occur about once a quarter only.

Lead Ore.—The usual method of sampling ordinary lead ore may be thus described:—

The ores are divided into four classes: (1) cobbed ore; (2) sieve raggings; (3) fine raggings; (4) slimes. Each variety of ore is heaped separately during the month. As the quantity added each day cannot always be of the same metallic produce, each heap at the end of the month is thoroughly intermixed by means of shovels. The heap is then flattened and divided into quarters by two main passages made at right angles to each other, the

intersection of the passages being at the centre of the heap. Samples of No. 1 cobbed, No. 2 sieve raggings, and No. 3 fine raggings are now taken according to the following rules. From the sides of the passage or wall of each quarter, as well as from each heap into which the original heap is subdivided, several shovelfuls of ore are taken, and the whole placed on a plate of iron 6 feet square, having sides 3 inches high.

The sample is then well mixed and again divided into quarters, mixed and subdivided if necessary in the same manner as already described, until one quarter of the pile is reduced to a weight of 25 or 30 lbs. When this is done, a man turns his back against the sample and the officer in charge marks the divisions on separate heaps, 1, 2, 3, 4. The officer then calls out which heap is to be rejected; if "second," then 2 and 4 are rejected, and 1 and 3 constitute the sample. The sample is then taken into the sampling-house, and by means of a large pestle and mortar reduced to grains not exceeding one-fifth of an inch in diameter. After passing the reduced ore through a sieve, it is again divided by quartering the heap until the quantity is lessened to 5 or 6 lbs. in weight, according to the number of samples required to be sent to the smelters.

This latter quantity (5 or 6 lbs.) is then reduced so as to pass through a sieve perforated with holes ½ or ¾ millimetre in diameter. Should the cobbed ore sieve or fine raggings be moist through exposure to the rain or other cause, the samples may be readily dried by placing them in a copper pan over the fire. A similar method is also observed in dividing, pulverising, and taking the samples of the slimes. When, however, the sample from the latter ore is already well mixed, about 6 lbs. is spread upon the bottom of the iron plate, and from several places a spoonful of ore is taken and put into a small bag. Each sample from 5 to 6 lbs. in weight is then dried, pulverised, and passed through a wire or perforated ½-millimetre-hole sieve. A slip of paper describing the ore is then put into each of the bags, which bags are then taken to the office where the process of filling sample cartridges is thus carried out. 1. Each bag is separately emptied into a copper pan and again well stirred and mixed. 2. The sample cartridges are now filled and both ends sealed. 3. On each cartridge, about 7 inches long and 1 inch in diameter, is endorsed the description and estimated weight of the parcel of ore, also date of intended sale. The cartridges are simply made of foolscap paper, one sheet being sufficient for two cartridges. The paper is rolled on a piece of round wood and the outer edge glued to the cylindrical surface.

Tin Stone.—The sampling of tinstone is conducted in the following manner. Assume the parcel to be 20 tons. 1. It is spalled to a suitable size for the stamping-mill. 2. The spalled pile is turned over and over by means of shovels so as to mix one portion uniformly with the other. 3. The "mixed" pile is divided into "doles" or parts, 20 tons, into say 20 doles. 4. Any one of these 20 doles is selected by the captain of the mine, weighed, and 10 per cent. of the weight deducted for water assumed to be contained in the dole. 5. The dole or ton sample is then cut through the centre for about a foot in width, and from the sides of this cutting a ½ cubic foot, a little more or less, is gently and carefully taken,

placed in a "sample box," and removed to the sampling-house. 6. The sample, broken to a uniform size, to about that of a walnut, is evenly distributed as a thin round layer on the "bruising pan." It is then divided by cuts through the centre at right angles to each other into four fairly equal parts, two of which, one at each opposite corner, being thrown aside. This dividing and rejecting operation is repeated four or five times, until the quantity is rendered sufficiently small to be semi-pulverised, when the sample is dried in a flat, low-edged pan over the fire. 7. The grains constituting the sample are now reduced to a finer state of subdivision, divided and rejected on the "refining iron," as described in No. 6, until a small bag constituting the sample for assay is obtained. 8. This sample is now handed to the "sample trier," who washes it on a "vanning shovel," and gets rid of most of the waste by a peculiar motion given to the shovel, the sample trier further pulverising the sample as may be necessary, so as to obtain a residue consisting chiefly of oxide of tin. 9. This residue or sample, if associated with iron or arsenical pyrites, is now roasted in a crucible for a period of twenty or thirty minutes until the sulphur or arsenic present is completely volatilised. 10. The roasted sample is then vanned, dried over the fire, and after the application of a powerful magnet for the purpose of extracting any magnetic particles which may be present, a tolerably pure oxide of tin is obtained. The value of the parcel of tinstone is then estimated—weight 20 tons, 1 oz. of oxide of tin, equivalent to 1 ton oxide of tin, market value £50 per ton. Then—

£50	0	0	will stand for	1 ounce	of oxide of tin.
2	10	0	,,	1 dwt.	,,
0	2	1	,,	1 grain	,,

Now let it be assumed that the sample in question gave 19 grains of black tin. 19 by 2s. 1d. will give a value of £1 19s. 7d., or for the parcel, 20 tons, the sum of £39 11s. 8d. The tools and apparatus used in the sampling operation are (1) steel ragging sledge, 7 lbs. weight, 6 × 2 × 1½; (2) steel spalling hammer, 3 lbs. weight, 6 inches long; (3) sampling or bruising iron, 2½ inches square × 2½ inches thick; (4) bucking iron, 4 inches square, 8 lbs. weight, convex face, hilt through eye or loop on top; (5) refining iron, flat, with smooth face; (6) bruising hammer used on refining iron, flat, 4 inches square, 3 lbs. weight; (7) bruising hammer used on the vanning shovel, flat, smooth surface at either end, weight 3 lbs.

The adventurers in various small tin mines in Cornwall, insufficiently explored to justify the erection of costly dressing machinery, sell their tinstone to a class of men known as "bargain buyers." In determining their offer for tinstone they usually deduct £10 per ton from the market price, and as the tinstone is commonly reckoned by the barrow, five of which are supposed to make a ton, the buyers also deduct 1s. per barrow, or 5s. per ton, and include both sums under the name "returning charges." Thus, if the market price for black tin is £50 per ton, the deduction will be (200s. + 5s.) £10 5s., and the net price £49 15s., upon which the value will be estimated. To obtain the actual weight of black tin in a ton of tinstone

corresponding to the number of grains or dwts. in a sample of 20 dwts., recourse is had to the following table :—

Number of Grains of Black Tin in Sample of 20 Dwts.		Yield of Black Tin per Ton of Stuff.				Number of Grains of Black Tin in Sample of 20 Dwts.		Yield of Black Tin per Ton of Stuff.			
Grains	dwts.	Cwts.	qrs.	lbs.	ozs.	Grains	dwts.	Cwts.	qrs.	lbs.	ozs.
1	0	0	0	4	10	12	0	0	2	0	0
2	0	0	0	9	5	18	0	0	3	0	0
3	0	0	0	14	0	24	0	1	0	0	0
4	0	0	0	18	10	0	2	2	0	0	0
5	0	0	0	23	5	0	3	3	0	0	0
6	0	0	1	0	5	0	4	5	0	0	0
9	0	0	1	14	0	0	5	6	0	0	0

The sampling of ores is, in many places, mechanically performed. In Chili and Bolivia, as well as in the principal mines of the desert of Atacania, a simple and effective apparatus is employed. At the Lebanon mine in Colorado a mechanical sampler is also advantageously used.

(N.) *Dressing Ore Floors.*—A site for a dressing-floor should, if possible, include the following advantages. 1. Ample room for the buildings, machinery, and waste hillocks. 2. Cheap transport of the vein stuff from the various shafts. 3. A natural and constant supply of water for jigging, buddling, and other dressing purposes. 4. A suitable fall of ground for gravitating, as it were, the stuff from one to another set of dressing-machines. 5. A good fall and sufficient area of ground for the disposal of the tailings. If the enriching machinery be of a simple and satisfactory character, such a site will admit of cheap and ready treatment of the stuff. There need be no lifting of the orey products for the various mechanical operations which it will have to undergo, and consequently no necessity for employing inverted wheels, cup-elevators, or lifts. To run the stone-breakers, crushing-mills, jiggers, and buddles, shafting, belts, and riggers may be satisfactorily employed, but in such case the machinery should be placed within covered building.

In many cases, however, a considerable fall of ground and a full supply of water are not obtainable, and recourse must be had to means for lifting the stuff and circulating the water.

In Cornwall, Wales, and elsewhere the stuff is frequently lifted from the floor to the rolls of the crushing-mill and to the pass of the stamps by means of a short wooden incline-plane, a waggon, chain, drum, clutch, and friction gear comprising a simple, cheap, and effective apparatus. For lifting rough vein stuff and coarse sand, cup-elevators are employed, mostly in the North of England, while slime, partly suspended in water, is passed from a lower to a higher elevation by a dipper-wheel or an Archimedean screw. In almost every instance in Cornwall, where the initial supply of water is insufficient for the various washing processes, it is supplemented as it were by returning it to the head of the dressing-floors by an ordinary plunger, which is preferable to a centrifugal or drawing pump. The machinery to be employed in the enrichment of ore is almost settled by common consent. For tinstone the reduction commences with the stone-breaker and stamps, while for copper, lead, and zinc ore hand-cobbing may

form the first stage in the operations, but reduction will be performed by the stone-breaker and the crushing-mill. From the crusher the sand is usually divided into slimes for buddles and sand for jiggers. In tin-dressing the jigger is not used, although it might be in many cases with considerable advantage; the stamped stuff either goes into strips or runs directly to round buddles and frames. The chief aim to be sought in effecting the mechanical separation of ore is to limit the number of the dressing-machines to the character and value of the ore, to shorten the dressing processes as much as possible, to minimise the loss of ore consequent on division and subdivision of the stuff, and to get a product not only suitable for the smelting furnace, but one which will bring into the coffers of the undertaking the largest amount of money.

Great Britain contains a considerable number of lead-bearing strata, enclosing veins of sulphide of lead and argentiferous ore. The former ore is mostly found in the Mountain Limestone, the latter in the older rocks. The outcroppings of some veins furnish carbonate, and occasionally stones of phosphate of lead, but the ore for the smelting furnace is, in nearly all cases, sulphide of lead. At Alderley Edge a limited quantity of carbonate of lead exists in a fine-grained Sandstone. Lead veins ramifying throughout the Limestone frequently contain compact galena and blende, while in Cornwall they carry the sulphide of lead, silver, copper, zinc, iron, and carbonate of iron. The veinstone or matrix accompanying lead ore often varies. In North Wales it consists of carbonate of lime, quartz, and silicious Limestone; in Derbyshire of carbonate of lime, quartz, and barytes; and in the North of England of quartz, carbonate of lime, fluor-spar, and barytes. In Devonshire and Cornwall fluor-spar and quartz frequently accompany the ore.

The ores of lead are mined and brought to surface in the usual way, either by shafts or levels. Compact galena associated with carbonate of lime, Limestone, or Slate rock may be quickly and cheaply dressed, but the complex ores adverted to will require both skill and care to separate them from the matrix, if a heavy loss of the metalliferous portion present is to be avoided. Blende, carbonate of iron, and copper pyrites, when associated together, being nearly alike in density, are scarcely separable by hydraulic means. In some cases these ores are dressed by dynamo-magneto apparatus. Formerly a considerable number of enriching operations were required to separate lead and blende ore intimately mixed with veinstone, but the use of the stone-breaker, sizing trommel, classifier, and improved buddle has materially shortened, as well as cheapened, the cost of the dressing process. The apparatus employed in the dressing of lead ore usually consists of a wash kiln, Fig. 192, or of a washing and dividing trommel; a stone-breaker, Figs. 193, 194, frequently fitted with a sizing trommel; a crushing-mill and dividing riddle, Figs. 195, 196; a classifier, Fig. 210; a separating cone, Fig. 211; a set of sizing trommels; coarse and fine sand jiggers, Fig. 213; a "fine" crushing-mill, or a small battery of stamps; side blow shaking tables and round buddles, Figs. 220 and 223.

At the wash kiln the stuff is usually separated into two classes, viz. stones too large to pass through the holes in the washing plate, and stuff sufficiently small to fall readily through such holes. The former product, the stones, are reduced in size, and furnish prill, dredge ore, and waste,

while the latter yields a similar set of products. The prill or pure ore is carried to the ore-house, the waste to the hillock, while the dredge is frequently cobbed, furnishing in turn pure ore for the ore-house, dredge for the stone-breaker or crushing-mill, and waste for the attle-heap. After the dredge has passed through the stone-breaker it is often divided into—

Roughs which furnish	Pure ore to ore-house. Dredge to crushing-mill. Waste to hillock.
Smalls which when sized and jigged yield .	Pure ore to ore-house. Raggings to crushing-mill. Skimpings to hillock.

The dredge and raggings, after they have passed through the rolls, are reduced to grain sizes from O to X, the latter (X) representing the diameter of the holes which may be in the riddle which is set underneath the rolls. If it be a "five-hole," that is, five holes per lineal inch, each being equal to a hole five millimetres in diameter, the grain size will range from 0 to 5 mm. This mixed lot of grains will now pass into a separating cone, the object of which is to obtain slime sand for the classifier and buddles, and to keep any fine gritless slime which may be present from passing into the jiggers along with the coarse sand.

Let it be supposed that the division happens to include on the one hand gritless slime, and slime sand for buddles, composed of grains varying in their dimensions from 0 to $1\frac{1}{4}$ mm., and coarse sand for jiggers, comprising grains $1\frac{1}{4}$ to 5 mm. diameter. The latter coming first in the sequence of dressing will be sized into grains—

$1\frac{1}{4}$ to 2 mm. and passed to No. 1 jigger 2 „ $3\frac{1}{2}$ mm. „ 2 „ $3\frac{1}{2}$ „ 5 mm. „ 3 „	each of which will furnish	Pure ore for ore-house. Raggings for fine crusher or stamps. Waste for hillock.

While the grit slime and slime sand may be classified into two or three sets of grains, each of which, enriched on a like number of buddles, will furnish pure ore for the ore-house, middles for retreatment, and waste for the hillock. The raggings, after passing through the fine crusher or stamps, will either run into a trommel to be sized and jigged, or into a classifier to be classified for enrichment in the buddles.

The ores derived from the Cardiganshire and Cornish veins do not perhaps contain on an average more than 5 per cent. of lead, which must be dressed to assay from 70 to 75 per cent. of metal. If the loss in tailings be reckoned at one-half unit of lead per ton of stuff, and the dressed product yields by assay 75 per cent. of lead, it follows that $16\frac{6}{10}$ tons of vein stuff will be necessary to afford one ton of ore. In 1856 the quantity of lead ore raised in the United Kingdom was 101,997 tons, which contained 73,129 tons of lead. In 1881 the total tonnage quantity had fallen to 64,702 tons of ore, representing 48,587 tons of metallic lead. The argentiferous ores of lead are obtained chiefly from Cornwall, Cardiganshire, and the Isle of Man.

The production of blende, which was mostly obtained from the lead veins, was confined to fifty mines distributed throughout the United Kingdom. For the year 1881 these mines afforded 35,527 tons of ore, which yielded 14,947 tons of metallic zinc.

In many Cornish mines the lodes contain both tin and copper ore. In some instances it has been found that copper mainly formed the shallower and oxide of tin the deeper portions of a lode, as, for example, at Dolcoath mine; while at Tregembo, near Hayle, sulphide of copper, arsenical iron pyrites, spots of sulphide of lead, and streaks of oxide of tin are found more or less aggregated together. The most abundant ore of copper is copper pyrites, a sulphide of copper and iron, containing, when strictly pure, 34·6 per cent. of metallic copper, 30·5 per cent. of iron, and 34·9 per cent. of sulphur. The other principal ores are the red and black oxides of copper, purple or single sulphide of copper, and blue and green carbonate of copper. The metallic percentage of each of these ores when in a state of absolute purity is :—

Copper pyrites	34·6
Red oxide of copper	88·8
Black ,,	79·8
Grey copper sulphide	77·1
Purple ,, (horse-flesh, sulphide)	70·
Green carbonate, malachite	57·3
Blue ,, azurite	55·1

None of these ores are very hard, all being readily scratched with a knife. The vein stuff, consisting of earthy matter and metalliferous ore, is raised from the levels in skips or kibbles, containing from 10 to 20 cwts. each. On reaching the surface the stuff is tipped into a waggon and transported on a tramway laid about 10 feet from the ground, which underneath is divided into stalls known as slides. Into these slides the stuff is tipped from the waggon. Then the dressing process usually commences; the larger stones are broken up with a sledge hammer called "ragging," and if a stone-breaker happens not to be a part of the plant the raggings are further reduced by spalling hammers to a size not exceeding the gauge of a ring 3 or 4 inches diameter. The whole of the stuff is now passed through two revolving sieves of different mesh, and then hand-picked by children and sorted into three qualities: (1) "prills," consisting of pieces of very nearly pure ore; (2) dredge, or second quality, in which the ore is more or less interspersed with the matrix; and (3) halvans, or waste. The prill ore (1) is riddled through ¾-inch square holes, and the two sizes are disposed of as follows :—

(a.) Fines, 0 to ¾ inch size	To pile for market.
(b.) Roughs, ¾ to 3 inch size, to crushing-mill and reduced to sizes 0 to ¾ inch.	

The dredge ore (2) undergoes crushing, classifying, sizing, and jigging. At Devon Consols, Captain Isaac Richards some thirty years ago employed in connection with the crushing rolls a set of sizing trommels, mounted successively end to end, and a classifying wheel, the former for sizing the grains into groups suitable for jiggers, the latter for obtaining equivalents for the buddles. The approximate disposal of the stuff from the crusher may be thus formulated :—

(c.) Sand (volumetric grains) to jigger.	(1.) Heads to pile. (2.) Middles reduced in crusher. (3.) Tails to halvan heap.	(1.) Heads to pile. (2.) Middles for retreatment. (3.) Tailings.
(d.) Slimes (equivalents) to buddles	(1.) Heads to pile. (2.) Middles retreated. (3.) Tails to halvan heap.	Heads to pile. Tails to halvan heap.

Owing to the increase of transport facilities throughout the world, and the consequent extension of the area of mining operation, copper-mining, as an industry, has become very seriously curtailed in this country. In 1859 Cornwall and Devon alone produced 182,391 tons of ore, containing 11,831 tons of metallic copper. In 1881 the quantity raised in the two counties was only 43,389 tons of ore, yielding 2,947 tons of metal. Thus the quantity of copper obtained from the ore raised in 1881 was barely 25 per cent. of the weight produced twenty-two years ago.

Tin ore, as already stated, exists in the primary rocks, diffused, or in distinct veins. Tin ore is also found in deposits, filling up low situations between hills, or in river beds, whence the name of stream tin has been derived. These detrital deposits are almost exhausted.

Ordinary tin veins in their characteristics do not differ from copper or lead veins. In some parts they contain very little of the ore sought for, being filled with sterile veinstone, or they may in places be so narrow as not to pay for working, or widen to such an extent as to enclose large deposits of ore. In some of the Cornish mines veins which were productive near the surface have been found poor for hundreds of feet in depth, then again rich for succeeding depths, a notable example being the present Dolcoath mine. This formerly was a rich copper mine, but from 130 to 180 fathoms below the adit the lodes were exceedingly poor, while at this time the lode at 420 fathoms from the surface is 40 feet wide, and is unusually productive in oxide of tin.

The merchantable ore of tin is a peroxide, which, when pure, contains 78·6 per cent. of metallic tin and 21·4 per cent. of oxygen. The impurities with which it is associated are mostly quartz, iron, arsenical and copper pyrites, and wolfram. The specific gravity of these minerals is such as to admit of their hydraulic separation into groups, but the separation of arsenical pyrites, from oxide of tin and wolfram, can only be effected after the former has been roasted and converted into oxide of iron, while wolfram can only be removed from oxide of tin by a chemical operation. On the assumption that tinstone contains the minerals referred to, and that these are liberated and properly classified, the following will be the approximate order of their separation:—

		Densities.		
GANGUE	Quartz	2·65 to 2·80	(1)	Separate approximately together.
	Chloride	2·65 „ 2·85		
	Slate	2·50 „ —		
ORES	Copper pyrites	4·10 „ 5·03	(2)	Ditto ditto.
	Iron pyrites	4·83 „ 4·30		
	Mispickel (arsenical pyrites)	6·00 „ 6·40	(3)	Ditto ditto.
	Peroxide of iron	6·50 „ 8·10		
	Wolfram	7·15 „ 7·55		

The black tin raised at present in Cornwall amounts to 1,000 tons monthly, to produce which, fully 60,000 tons of tinstone have to be stamped to a fine powder, and subsequently submitted to a complicated series of manipulations. In its rough state the average value scarcely exceeds £1 per ton, while at present prices dressed ore or black tin may be taken at £55 per ton.

An analysis of a parcel of black tin, dressed and ready for sale, gave, according to Moissenet, the following results:—

Oxide of Tin	92·00	Oxide of Tin	93·66
Oxide of Iron { Combined	1·66		
Oxide of Iron { Free	2·66	Gangue	4·32
Stony gangue	1·66		
Water	2·00		2·00
	99·98		99·98
Metallic Tin		72·312	

A microscopic examination of grains of veinstone, and minerals, from the stamp-grates shows that they take the form of larger fragments of the same substances; that is to say, the grains present similar irregular and angular appearances. Several conditions exist in Cornwall which prevent a quick, ready, and cheap concentration of the black tin associated with mixed ores and gangue: (1) The tin stuff from the grates often clot into small patches. (2) These patches do not break up at the proper place in the dressing apparatus; consequently, the black tin which they retain is not deposited in the position assigned to it. (3) The water used in dressing, rendered viscid by the stamping process, retains the finer grains of tin in suspension. (4) The viscid character of the water is not only detrimental to a good classification of the grains, but, if slightly charged with sand, it exercises an erroding effect on the rough or broken surface of the stuff deposited on the enriching tables. (5) A portion of the grains passed through the grates often contains highly minute grains of black tin, less than 0·01 mm. in diameter, which fail to settle at the head or even at the middle of the first enriching tables.

It therefore follows that the loss of black tin in the tailings must always be an appreciable one. The best authorities on this subject have, after numerous experimental trials, arrived at the conclusion that the tailings from the enrichment of tinstone may be regarded as containing from 2 lbs. to 3 lbs. of black tin per ton. Taking the higher expression as more nearly approaching the fact, it follows that the oxide of tin included in the waste, and lost to the mines, exceeds 900 tons yearly.

The cost of stamping and dressing tinstone to afford 1 ton of black tin differs to a slight extent in almost every mine, but if the dressing be economically done the stamping will be about 1s. 9d. and concentration 1s. 6d., or together 3s. 3d. per ton. In some cases, however, the cost of stamping and dressing will amount to 4s. per ton of stone. The normal dimensions of tin grains differ in stuff taken from the same lode, while a mine may have two or three lodes each affording a "different grained tin," and marked differences in the composition of the gangue. Tin capels, almost without exception, contain fine grain tin, and should be reduced so as to pass through a fine grate, say 36 holes to the lineal inch, while coarse-grained tin may be satisfactorily released from the matrix if stamped so as to pass through grates 30 or 33 holes per lineal inch.

The machinery employed for the purpose of dressing tinstone includes the stamps for reducing the stone into grains, varying in their dimensions from 0 mm. to ¾ mm.; the centre-head buddle and concave buddle, for getting rid of a portion of the waste; the tossing or packing-tub, for further separating waste from the oxide of tin present; the calciner, for roasting or calcining the partially-dressed tin stuff or *whits* so as to get rid of a

arsenic or sulphur with which it may be associated; the pulveriser, for reducing the roughs to a gritless sand; and the slime frame, for concentrating the black tin contained in such sands. Distinct opinions prevail upon various questions connected with the enrichment of tinstone; one dresser asserts that it should pass from the stamp-grates into drags or strips, and undergo a partial concentration within this apparatus; another that strips are unnecessary, and that the stuff should go direct to the buddles, while other dressers take exception to one dressing-machine and prefer another; thus the use of Williams's buddles will be advocated in one district and objected to in another, while opinion would seem to be almost divided as to the respective merits of the centre-head and concave buddle. It were much to be wished that the dresser would properly classify the tin stuff in front of the stamps, when, with suitable apparatus, the dressing operation might not only be simplified, but the loss of black tin in the tailings would be lessened, although it can never be absolutely prevented. These observations will be found to acquire weight from remarks on tin-dressing by Captain Charles Thomas, of Cook's Kitchen, contained in a paper read at a meeting of members of the Mining Institute of Cornwall.

"From the Mineral Statistics for 1881 it appears that five Devonshire and ninety Cornish mines raised together 12,898 tons of black tin, and that 957 tons were obtained from streams, rivers, and foreshores, being nearly $\frac{1}{13}$th of the whole in weight, or in money value $\frac{1}{19}$th. This quantity is actually returned, but how much more runs into the Atlantic cannot be ascertained. It is certain, however, that after passing over three or four miles of frames set in the Red River the stream workers close to the sea earn a livelihood from the 'waste' sent from our mines. In stamping tinstone the grateways are often too small. At Cook's Kitchen the front grates are 28 inches long by 9 inches high, the end grates 9 inches long by 9 inches high. The size of hole depends on the nature of the stuff stamped. In process of stamping the tinstone is divided into three classes—'crop tin,' 'fine tin,' and 'dredge.' The 'dredge tin' is that small proportion found in the 'rows,' the 'heads' of which are generally restamped or pulverised. This is the least important portion of the tin, and can be easily secured. The 'crop tin,' too, on account of its high specific gravity, is also easily collected, but the 'fine tin' is only partly obtainable after frequent and careful manipulation. It is this fact which gives value to the 'tin streams,' the fine black tin being carried into them in large quantities as slime tin.

"The great question to solve in tin-dressing is, how can the slimes be 'untinned'? The practical conclusion forced upon me is this: The round buddle in front of the stamps receiving the 'slimes' and 'rows' is effectual inasmuch as the 'rows' untin the 'slimes.' In other words, the 'rows' form a kind of filter through which, assisted by the buddle sweeps, the slime tin is filtered. The dimensions of the buddle are—external diameter 21 feet, with a 10 feet centre-head, which leaves an annular working floor 2½ feet wide. This floor is approximately divided into the head, 1 foot 6 inches wide, crease, 2 feet wide, and tail, 2 feet wide. Such a buddle will dispose of the stuff reduced by 12 or 16 stamp heads. In stamping stuff producing, say, 40 lbs. of tin to 1 ton of stuff, the head may be buddled once, tossed once,

and immediately calcined, while in stuff producing 75 to 100 lbs. of tin to the ton, the head may be calcined at once. Thus it is possible to take out 80 to 85 per cent. of the produce in the first process without having recourse to barrow, shovel, or manual labour other than the labour necessary for removing the stuff to the calciner. Repeated trials have given similar results. For example, from a parcel of tin stuff containing 13 cwts. of black tin, produce 5 per cent., 10½ cwts. of black tin were obtained from the head of the buddle and carried direct to calciner. The great advantage of this method arises from the fact that the 'slimes' are rendered quite 50 per cent. poorer than by the ordinary process of tin-dressing."

The "slimes" run direct to the slime pit, after which they pass first over a set of centre-head buddles, and then over frames.

The "rows" containing the "dredge tin" are deposited in strips, and the heads restamped or pulverised; but it might be suggested that the "rows" *at this point* be put through a jigger to separate the remaining portion of the slimes. The "rows," or such portion of them as may be found profitable, should then be pulverised. At Cook's Kitchen one of Michell and Tregoning's pulverisers reduces about 6 tons in 24 hours.

With respect to the tin yard, and the treatment of the burnt leavings, many dressers return these to the stamps; but by far the best method is to pulverise them. Stuff of this nature, containing as it does about 15 per cent. of black tin, and, being highly "corroded," requires very careful treatment. The present mode of paying the dressing pare is defective. In many mines from £1,000 to £2,000 worth of tin stuff is treated monthly, and as only about 2 per cent. of this stuff consists of black tin the concentrating process is necessarily tedious, and requires careful and intelligent superintendence. The dresser superintending the stamp floors or frames has almost the sole responsibility of treating the tin stuff, yet for his supervision he usually obtains but £3 5s. or £3 10s. per month! Able miners at the same time get £4 10s. to £5 per month. Now what is there for a man of even average ability to aspire after in the tin-dressing department? Nothing except the solitary chance of becoming a "captain dresser." Our overlookers, like enginemen in the Cornish mines, are underpaid, and the consequence is that they watch the ringing of the bell with far greater anxiety than the interests of adventurers. A man of moderate ability in any department of labour, if he carries an extra responsibility, must be paid for it. Overlookers must feel an interest in their work, and efficient men are made mainly so by healthy competition with others, and where there is nothing worth competing for good men will not compete.

The following description of tin-dressing as conducted at Wheal Agar, Redruth, has been kindly furnished by Mr. Bedford McNeill, Associate of the Royal School of Mines. The tinstone is reduced by means of the stamps just sufficiently fine to liberate the black tin from the associated veinstone, and the stuff having passed through a No. 36 copper grate, perforated with holes barely one-half of a millimetre in diameter, is conveyed by means of a launder into the middle of a centre-head buddle. The portions richest in tin are deposited nearest the crown, while the stuff diminishes in richness to the circumference, the slimes going away into settling-pits. As

soon as the buddles which may be designated No. 1 are full, the stream is diverted into similar buddles No. 2. The "dresser" having examined the "work" in No. 1 buddles, determines how much shall be considered (1) "heads," (2) "middles," or "crease," (3) tails. The stuff is now shovelled out, care being taken to keep each of the foregoing classes separate, and the buddles, when empty, are ready for a second operation. As soon as a sufficient quantity of "heads" from buddles No. 1 have accumulated they are subjected to a second buddling operation, which is performed in concave buddles. In this machine the "heads" are found at the circumference, whilst the stuff decreases in richness to the centre, from which the waste flows away to settling-pits. The "heads" from buddle No. 2 still require to undergo a third or even fourth operation, for which concave buddles are again used, by which time the "heads" produced are, as a rule, sufficiently rich to be "tossed." Both this as well as the subsequent operation of "packing" is performed at some mines mechanically, but at Wheal Agar it is done by hand. The "tossing" is carried out in large tubs or kieves, which are first partly filled with water, and into which a charge of the richest "heads" is gradually added, the whole being kept thoroughly agitated until the kieve has received the full quantity; the agitation is now discontinued, and the kieve is smartly tapped or packed on the outside by means of an iron bar. The passage of the heavier or richer particles of stuff to the bottom of the kieve is thus accelerated, whilst the poorer and lighter portions collect towards the top. The whole is then allowed to stand, after which the water is removed. The top portion or skimpings are put aside for subsequent buddling, while the remaining contents of the kieve are considered fit for the burning-house. The numerous divisions of stuff of varying richness thus obtained by the foregoing operations are buddled and rebuddled with a view of gradually eliminating the sterile portions. From the slime collected in the settling-pits the main bulk of water is first drained off, when the slime is gradually washed into a launder by means of a small jet of water, and is so carried to one or more concave buddles. These give an enriched product for still further concentration, "tails" which go to "frames" whilst the slimes are conveyed to settling-pits. It is the ultimate product of these operations, or "slime tin," which so greatly taxes the ingenuity of the tin-dresser to secure, the water stealing away as it were to a considerable extent the finer portion of the slime tin present. In the subsequent process of calcining, on account of the excessive fineness of the slime tin, it is necessary to treat it distinct from the coarser product obtained in the main buddling operation.

Calcination or burning has for its object the removal of the sulphur and arsenic, occurring as mundic and arsenical mundic along with the oxide of tin. The sulphur is converted into sulphurous anhydride and totally lost, whilst the arsenic is volatilised and condensed as arsenious acid in a series of long flues built for that purpose, and becomes "crude arsenic," a source of revenue to the adventurers. Formerly the burning was accomplished in a reverberatory furnace, having a large square hearth and low roof. Such furnaces are now, however, almost exclusively reserved for the treatment of slime tin, whilst mechanical calciners, as Brunton's or Oxland and Hock-

ing's, are employed where the production of black tin is such that they can be kept continuously at work. In Brunton's calciner, at Wheal Agar, the charge previously dried is fed from above on to the centre of a revolving circular hearth, a series of "flukes" or iron stirrers gradually turning the stuff over until it reaches a point near the circumference, where a "scraper" removes it from the bed altogether into the "wrinkle," the speed of the bed being so regulated that the stuff shall be roasted "dead" or "sweet" before it reaches the "scraper." The burnt product in the wrinkle whilst hot is usually cooled with water, and is then treated in a series of centre-head buddles, the slimes from which go to a settling-pit, whilst the tailings or burnt leavings reduced still finer by means of Michell and Tregoning's pulverisers, Fig. 202, are re-buddled. The heads from the first buddle are again treated, and so progressing to the tossing and packing operations, are gradually brought into the marketable condition known as black tin. All the various sizes of black tin obtained at various stages of the dressing process are thoroughly mixed so as to send a uniform product to the smelting-house. Oxland and Hocking's calciner may be briefly described as a huge inclined cylinder revolving on its axis, with the fireplace at the lower end, while the "whitts" are fed at the upper end, and gradually part with their sulphur and arsenic during their passage through the length of the cylinder.

The machinery requisite for the enrichment of distinct classes of ore cannot well be grouped within the limits at our command. The quantity of stuff to be disposed of within a given period, the value of the ore, the character of the veinstone, the difference of density between one substance and another, the price of labour, together with other direct or collateral circumstances, must carefully be considered. But in most cases the machines enumerated in the following list may be successfully applied for the purposes stated:—

REDUCING MACHINERY.

1. *Stone-breakers*	For reducing to fragments hard and non-elastic stuff, for the cobbing process, crushing stamps, and disintegrators.
2. *Crushing Mill* . . .	For reducing to grains stuff for jiggers and buddles.
3. *Disintegrators* . . .	For reducing stuff to sand for jiggers or buddles.
4. *Stamps*	For reducing stuff for treatment in fine sand jiggers, buddles, or tables.
5. *Edge-runners, Horizontal Mills, and Pulverisers* .	For reducing dredge-grains to size suitable for treatment on buddles and tables.

WASHING APPARATUS.

1. *Kilns*	For disintegrating and freeing veinstone, in order to render it suitable for hand-picking, cobbing, stone-breaker, and crusher; also partly for the sizing trommels and jiggers.
2. *Wash Trommels* . . .	Ditto.

SIZING AND CLASSIFYING APPARATUS.

1. *Trommels (volumetric grains)*	For sizing stuff, sometimes for hand-picking, but chiefly for coarse and fine sand jiggers.
2. *Single and Divisional Classifiers, Ascending Columns, Dividing Cones, and Pyramidal Boxes (equivalent grains)* . . .	For classifying stuff for fine sand jiggers, buddles, and tables.

CONCENTRATORS.

1. *Rotatory Separator* .	For freeing sand from slime, and partly classifying the sand for jiggers
2. *Jiggers*	For getting rid of worthless vein stuff and increasing the metallic percentage of the resulting product for subsequent treatment.

SEPARATING AND ENRICHING MACHINERY.

1. *Rough Jiggers* . . . For dividing stuff into (1) castaways, (2) orey stuff, (3) ore, the stuff ranging in size from 10 mm. to *x*.
2. *Coarse Sand Jiggers* . For separating grains from 3 mm. to 10 mm., into (1) waste, (2) orey stuff, (3) ore.
3. *Fine Sand Jiggers* . For separating sand from $\frac{3}{4}$ mm. to 3 mm., into (1) waste, (2) orey stuff, (3) ore.
4. *Slime Sand Jiggers* . For separating sand from 0 mm. to $\frac{3}{4}$ mm., into (1) waste, (2) orey stuff, (3) ore.
5. *Convex and Concave Buddles* For separating sand from $\frac{3}{4}$ mm. to 2 mm., into (1) waste, (2) orey stuff, (3) ore.
6. *Side and End Blow Tables* . For separating sand from 0 mm. to $\frac{3}{4}$ mm., into (1) waste, (2) orey stuff, (3) ore.
7. *Brunton's and Slime Tables*. For separating sand from 0 mm. to $\frac{1}{2}$ mm., into (1) waste, (2) orey stuff, (3) ore.
8. *Dead Frames* . . . For concentrating fine tin or lead slimes into (1) waste, (2) tin or orey stuff, (3) black tin or ore.

GENERAL TABLE RELATING TO ORE-DRESSING MACHINES.

—	Approximate Quantity worked per 10 Hours.	Approximate Horse-power required.	Gallons of Water required per Minute.
	Cwts.		
Rotating Picking Table	200	$\frac{1}{20}$	—
" " Band	150	$\frac{1}{20}$	—
Common Skimming Jigger, coarse stuff	$2\frac{1}{2}$ Per sectional inch.	$\frac{1}{10}$	$1\frac{1}{2}$
" " . " fine " .	2 Per sectional inch.	$\frac{1}{10}$	$1\frac{1}{2}$
Kember's Continuous Jigger . .	20 Per sectional inch.	$\frac{1}{4}$	15
Continuous Coarse Sand Jigger . .	15 Per sectional inch.	[illegible]	20
" Fine " " . . .	8 to 10 Per sectional inch.	$\frac{1}{4}$	18
" Sand Slime " . . .	5 " 6 Per sectional inch.	[illegible]	15
Round Buddle	variable	$\frac{1}{10}$	—
Concave Buddle	"	$\frac{1}{10}$	—
Side Blow Table	100	[illegible]	14
End "	100	[illegible]	7
Dead Frames	—	—	—

CHAPTER V.

DISCOVERY AND EXTRACTION OF IRON ORES FROM VEINS AND OTHER DEPOSITS.

Iron Ores of the United Kingdom.

	Localities from which they are principally obtained.
Native Iron— *Meteoric Iron*	Greg and Lettsom* give a list of 20 British meteoric stones, with date of fall.
Magnetite— *Magnetic Iron Ore*	Cornwall—Redruth, St. Agnes, Roche, Penryn. Devonshire—Haytor, Brent, Tavistock. Scotland—Portsoy, Shetlands, Isle of Islay, Isle of Bute. Ireland—Antrim.
Specular Iron— *Red Hæmatite* *Red Iron Ore*	Cornwall—Pool, St. Just, Lostwithiel. Devonshire—Hennock. Lancashire—Ulverston, Whitehaven. Scotland—Ayrshire.
Göthite— *Hydrous Oxide of Iron*	Cornwall—Lostwithiel, Redruth, St. Just, St. Austell. Devonshire—Shaugh, Tavistock.
Limnite— *Brown Hæmatite* *Bog Iron Ore* *Wood Iron Ore*	Cornwall—Lostwithiel, St. Just, Perran, St. Austell. Devonshire—Dartmoor, Brixham. Somersetshire—Brendon Hills, &c. Durham—Weardale. North Wales. Ireland—Antrim, Leinster, Ulster, Wicklow. Scotland—Lead Hills, Shetland.
Siderite— *Spathose Iron* *Carbonate of Iron*	Cornwall—St. Just, Perranzabula, St. Austell, Lostwithiel. Devonshire—Plympton, Tavistock, Christow, &c. Somersetshire—Brendon Hills, Exmoor, Toy Bridge. Durham—Weardale. Scotland—Isle of Arran, Orkney, &c.
Ilmenite and Iserine— *Titaniferous Iron Ore* *Menaccanite*	Cornwall—Menaccan, St. Kevern. Cheshire—Birkenhead. Scotland—Argyleshire, Shetland.
Vivianite— *Phosphate of Iron*	Cornwall—St. Agnes, St. Just. Devonshire—Tavistock. Lancashire—Furness.
Pyrites— *Iron Pyrites* *Sulpide of Iron*	Cornwall—Abundant in mines. Devonshire—Ditto. Cumberland—Alston, Nenthead. Scotland—Perthshire, &c. &c. Ireland—Antrim, Wicklow, &c.
Pyrrhotine— *Magnetic Iron Pyrites*	Cornwall—Botallack, Truro, &c. Devonshire—Beeralston, Brent, Ilsington. Ireland—Donegal, Fermanagh.
Mispickel— *Arsenical Iron*	Cornwall—Abundant. Devonshire—Devon Great Consols, Tamar mines. Scotland—Aberdeenshire. Ireland—Waterford, Wicklow.

Iron Ores not from the Coal Measures.—Iron ores occur sometimes in well-defined lodes, often in beds, and not unfrequently filling cavernous spaces in the Limestone rocks, or the cavities in the upturned edges of the older strata.

* "Manual of the Mineralogy of Great Britain and Ireland." By Robert Philips Greg, F.G.S., and William G. Lettsom.

The following notices of the geological conditions under which iron is found, the mineralogical characteristics by which the ores of iron are distinguished, and the commercial value of the different varieties of the ores of irons are mainly due to Mr. Richard Meade,* who has made the iron and steel industries of the United Kingdom the subject of his especial studies.

The ores of iron which do not belong to the Coal Measures are widely diffused through the rocks of Great Britain. The ironstone measures of our coal fields furnished, at an early period, upwards of three-fourths of all the ironstone smelted in our blast furnaces. The supply in recent years from the same source does not exceed 40 per cent. of all the ferruginous ore raised in the kingdom. With the growing demand for iron in the early years of the development of our railway system, when the ironstone obtained from our Coal Measures was insufficient to meet the requirements of our ironmasters, a great impetus was given to the discovery of other sources of supply, leading eventually to the development of the deposits of the North Riding of Yorkshire, or the Cleveland district, in the Middle Lias or "Marl stone," in Lincolnshire, to those of the Lower Lias, and in Cumberland, Lancashire, and other districts in the Carboniferous Limestone, supplemented by the rich hæmatitic ores imported from Spain.

Geological Conditions under which Iron Ores occur.—At the base of the Lower Silurian strata iron ores have been traced, though not worked to any extent; these deposits are enclosed in the Skiddaw slates, a strata described as consisting "of many alternations of mud, sand, and grit deposits, now converted into Slate, Sandstone, and gritstone," in some localities metamorphosed. The locality in Cumberland in which these deposits occur is principally in the neighbourhood of Skiddaw. Hæmatite deposits in well-marked veins are also recognised in the same rocks traversing Hunstone Crag and Low Wood from north-east to south-west; but hitherto these deposits have not been wrought.

Again, in the Granite of Ennerdale and Esk, in the same county, numerous lodes occur, which have been worked to some extent. Other varieties have been traced in the Ash and Felstone rocks of the neighbourhood, where they are well defined, and have been traced for nearly three-quarters of a mile to the Keswick side of the mountain from Ore Gap. The Granite of this area is tolerably uniform in its appearance, for the most part red, due to the colour of the felspar, modified, however, by the few dark specks of hornblende, and occasionally by mica and transparent colourless quartz. The Skiddaw Granite gives an analysis 75·223 per cent. of silica, 11 per cent. of alumina; the Eskdale Granite 73·573 per cent. of silica and 13·75 per cent. of alumina; the Ennerdale variety giving 67·180 per cent. of silica and 16·650 per cent. of alumina. Some attempts have been made to work the few lodes which occur in the Ennerdale district, but they have not proved profitable. These lodes have been referred to as the source from which the Whitehaven deposits have been derived, but such an hypothesis is untenable.

The other localities in the United Kingdom of Silurian age, in which iron

* "Coal and Iron Industries of the United Kingdom of Great Britain." By Richard Meade. Crosby Lockwood & Co.

ore is known to exist, are chiefly in the County Wicklow, in lodes in the Ballymurtagh and Cronebane mines enclosed in Clay-Slate, in the counties of Longford and Cavan in the Lower Silurian rocks. Facilities for their development are, however, wanting in the way of canal and railway communication to the coast. The districts referred to in Longford lie between Granard and Carrick-on-Shannon, and in Cavan between Ballyhoy and Cavan.

Devonian Formation.—The deposits of ore found in the Devonian rocks are of the varieties known as spathic, brown, red, and magnetic ores; in Somersetshire the spathic deposits are found enclosed in the upper division of the Middle Devonian, known as Clay-Slate. These rocks near the surface are of a greyish colour, acquiring in depth a green or bluish tint. The Brendon Hills, in which spathose ores occur, range nearly east and west at about 6 miles south, between Watchet and Minehead, and terminate in a deep valley near Eisen Hill, in which similar deposits are found. On Exmoor several lodes of this ore are known.

In Devonshire, magnetic ores occur in well-defined lodes at Haytor, near Ilsington; in the Clay-Slate of that district, the direction of the strata in which they are imbedded being nearly north-west and south-east, underlying at the north-east at an angle of 22° or 23° for the first few feet from the surface; below this, however, the dip is very regular at an angle of 45°. At Smallacombe, also near Ilsington, in the decomposed Clay-Slate of the district, brown hæmatite occurs in nodules forming irregular beds in a thick mass of variegated clays, the innumerable layers of which slope gently a few degrees only from the horizontal to the south-east.

In another locality, at Hennock, near Bovey Tracy, north of Ilsington, a micaceous variety of ore is found bearing east and west in a close-grained porphyritic Granite. This lode has been worked open to day for more than a mile. At Buckfastleigh, in the South Devon mine, imbedded in Killas and Limestone, brown hæmatite occurs. Again at Torbay, on the south coast, near Brixham, a similar variety is found in the Devonian Limestone, which is tilted at a considerable angle, and presents a broken appearance near the surface, the fissures containing the ore having, it is said, a direction east and west. In North Devon and West Somerset, extending from Ilfracombe to Bridgewater, iron lodes have been discovered, occurring both in regular strata and veins, often tilted with the shales in which they occur, and at such considerable angles as to render their working difficult.

In Cornwall one of the most important deposits is that of Restormel, held under lease from the Duchy of Cornwall. The sett containing this deposit extends north and south for 1¾ mile, and is enclosed in Clay-Slate or "Killas," dipping to the east. Brown hæmatite is also known to occur in several localities in a line coincident with the magnetic meridian, coursing from a point a few miles east of St. Austell on the south, to the estuary of the Camel at Padstow on the north, namely at Ruby, Kinghtor, Treverbyn, Coldvreath and Retiire, Withiel and Pawton. The lode at the last-named mine, situated 5 miles from Padstow and 3 from Wadebridge, occupies a distinct fissure in the Clay-Slate, the Killas of this district being brownish red, rather soft, and readily decomposing when exposed to the air. Cold-

vreath and Retiire produced in 1881 1,400 tons of iron ore, and 330 tons were shipped from Padstow, obtained from Lanivet and other mines in this locality.

The most extensive iron ore deposit in Cornwall is at Perranzabula. The Perran lode, as seen on the north coast of Cornwall, consists of two great branches divided by a horse of Clay-Slate. Considerable explorations have been made at Great Retallack and at the Duchy and Peru mines, now worked for zinc as the Duchy mine. Many other localities in Cornwall are known to yield iron ore; of these the district of Constantine, west of Falmouth,—the Ruthers mine, near St. Columb, and the Indian-Queens and Trelivian mines, near St. Austell, may be referred to as the more important.

Carboniferous Limestone.—The chief varieties of iron ore developed in this series of rocks are nodular carbonate, brown and red hæmatites, and spathic ores. In Northumberland, at Ridsdale, in the Carboniferous Limestone series, as well as in a few other localities, at Brinkburn and Rothbury, nodular ironstone (carbonate) has been obtained; the quantities, however, were never considerable. The brown hæmatite of Dean Forest, in *Gloucestershire*, was first worked about the year 1650, and as the rich character of the ore became better known the deposits were more fully developed. The mineral basin of Dean Forest has a superficial area of about 34 square miles, and is more perfect in form and outline than any other coal field in Great Britain. The iron-ore deposits are enclosed in the stratified masses of the Limestone in extensive hollows, or chambers, caverns, or churns, which occur in the dip of the enclosing strata, near the outcrop or basset on the eastern side of the Forest, decreasing gradually towards the centre of the basin.

Cumberland and Lancashire.—Iron ore of carboniferous age is well developed in the Mountain Limestone around Whitehaven, where it consists, in its lowest part, of about 250 feet of massive Limestone, reposing upon that division of the Lower Silurian system known as Skiddaw slates. The principal masses of ore are found in large irregular deposits, occasionally in the form of shallow fissures, also in flat deposits following more or less closely the dip of the beds, which have an inclination of from 12° to 18° to the west, or filling caverns in the Limestone. The area of these deposits in the Whitehaven district from south-west to north-east extend a distance of about 8 miles, with an average width of 1 mile, while in the neighbourhood of Millom the ore-bearing Limestone occupies an area of 1½ square mile. In Lancashire, as in Cumberland, the hæmatite deposits are found under nearly similar conditions; there are, however, some points of difference in the deposits of the two areas very clearly set out by Mr. J. D. Kendall, F.G.S.,* who, in his valuable paper, divides Furness into two districts, the one including the high ground northward from Ulverston as far as the head of Windermere and for several miles on both sides of Coniston Lake, a part of the Lake country; the other the low-lying ground, a continuation of the long narrow belt in West Cumberland which lies between the sea and the western hills of the Lake country. The mode of occurrence of hæmatite in the Furness districts is not confined to irregular deposits in the

* "Hæmatite Deposits of Furness." ("North of England Institution of Mining and Mechanical Engineers," vol. xxxi. 1882.)

Limestone, it also occurs in fissures more or less regular, having a north-west and south-east strike, with a dip to the south-west.

Alston Moor and the Weardale Districts of Northumberland and Durham.—Here the spathic and brown hæmatite ores obtained from the Carboniferous Limestone are found occurring in veins traversing the Limestone. In the lead-mining districts of Allenheads and Weardale, spathose ores occur in regular lodes, and in the flats which insinuate themselves laterally into the Limestone. These deposits at Weardale have been extensively quarried.

Lower Lias.—In North Lincolnshire, in the districts of Frodingham, Appleby, and Brigg, important deposits of iron ore have been developed in recent years, giving rise to great and growing mining industries in a district previously agricultural. In the north-western area of the county, the rocks dip in a direction from west to east, and comprise Liassic and Oolitic strata. The important ironstone deposit of the area of the district around the village of Scunthorpe is described as commencing below with a hard band of Limestone, intercalated with softer bands of a dark brown texture, intermingled with a brown earthy deposit. The Lower Lias clay in this area has a maximum thickness of 90 feet. The bed containing the ironstone in this district attains, in some places, a thickness of 27 feet, and is found but a little below the surface. There are other localities where ironstone has been worked in some quantity, as at Kirton Lindsey, north-east of Gainsborough; at Caythorpe, north of Grantham; at Claxby and Caistor; and at Monk's Abbey and Greetwell, near the city of Lincoln.*

Middle Lias or Marlstone.—Brown Oolitic, and ores of argillaceous carbonate of iron, exist abundantly in this division of the Lias. The Liassic rock covers a large area, extending from Wiltshire in the south to the North Riding of Yorkshire or Cleveland district, the area of greatest development being in the last-named district. The Cleveland Hills, containing the great repositories of argillaceous iron, extend from Ormesby on the north, near Middlesborough, to the coast, and in a southerly direction to the valleys of Eskdale and Rosedale. It is observed of this important deposit that its greatest development appears in the northern area of the field, diminishing both in the thickness of the beds and the quality of the ore in its extension to the south and east of the area.

The other localities in which these ores of argillaceous carbonate have been wrought are situated chiefly in Oxfordshire, at Adderbury, Aynho, Fawler, and in the neighbourhood of Banbury, near Woodstock. At Fawler the ore deposits lie upon soft sands, composing the lower division of the Marlstone, being surmounted by the clay of the Upper Lias.

Lower Oolitic (brown oolitic and magnetic ores).—The iron ore occurring in this stratum is found in the subdivision known as the "Northampton sands," ironsand and Sandstone, the equivalent of the Stonesfield slate, reposing on the Upper Lias clay. In the north of the county and on the borders of Leicestershire the bed of iron ore is well defined extending for miles along the Midland Railway to Finedon, and thence to Wellingborough, Blisworth, and on to the town of Northampton. One interesting

* For a detailed account of the ironstone deposits of North Lincolnshire, the Rev. T. H. Cross's paper, in the "Journal of the Geological Society of London," vol. xxxi., 1875, p. 115, should be consulted.

feature in the working of these deposits is that the covering or soil, being but a few feet in depth, is easily removed, exposing the iron ore. When the iron ore is removed the soil is restored, and the land is then available for agricultural purposes, its appearance not even suggesting that the ground had been disturbed.

Magnetic iron ore has long been obtained from the lower beds of the Lower Oolite, in a seam known as the "Dogger Bed," well developed in the Rosedale Abbey mines; it is also known as the "top seam," and is regarded as the equivalent of the Northampton sand.

Middle Oolite.—In a division of the Middle Oolite, deposits of iron ore are found, the coral rag in which the ore occurs being described as consisting of beds of fossiliferous Limestone containing corals and shells in a fragmentary condition. The chief locality is at Westbury, in Wiltshire, where it has been worked for many years.

Lower Cretaceous (brown and calcareous ores).—This formation, including the Wealden, has two great divisions, the Weald Clay and the Hastings Sand, upon which reposes the Lower Greensand. It is in this subdivision and high up that the iron ore occurs in reticulating veins, crossing in all directions the sandy strata in which they lie. The Lower Greensand strata in the Isle of Wight are considerable, giving in section, when well developed, upwards of 900 feet. The iron ore hitherto worked in the Lower Greensand has been found in deposits occurring at Seend, in Wiltshire, at Linslade, in Buckinghamshire, and at Tealby, in Lincolnshire. None of the above-named deposits, however, have been worked recently.

Miocene.—The most recently developed deposits of iron ore in the United Kingdom are those of the County Antrim, in the north-east of Ireland, occurring in rocks of Miocene age in the Tertiary system. The basalt, through which the iron ore is interstratified, is generally referred to as being divided into three classes: the amorphous, the columnar, and the concretionary, the varieties of ores wrought being known as brown, aluminous, pisolitic, bole, and lithomarge. An interesting paper, describing the iron ores of the County Antrim, has been written by Mr. J. D. Kendall.* The chief localities producing these ores are situated at Ballymena, Glenravel, Portrush, Glarryford, and Glenariff; Bauxite being obtained at the Irish Hill and Straid mines, near Ballymena.

Beyond this general statement of the geological condition under which the iron ores of the United Kingdom are found, it appears necessary to direct attention to a few of the phenomena which attend the varied deposits upon which explorations have been carried out.

The iron ore occurring in the Skiddaw slates appears in well-marked veins which have been occasionally worked. The chief of these have a general north and south trend upon the hills between Buttermere and Ennerdale Lake; eastwards from Helvellyn there is a large vein running east of Kepplecore Tarn, across the lower end of Red-tarn Beck, to the foot of Nab Crag, and probably through a gap in the Glenridding Screes; and other lodes in Patterdale, crossing from north-west to south-east, occur, but these veins have not yet been opened out.

* *Colliery Guardian*, 27th October, 1876, p. 657.

The lodes traversing the Granite of Eskdale and Ennerdale have a general north and south direction, often but a few inches in thickness, but occasionally reaching from 10 to 12 feet. In Ireland, as already stated, hæmatite of Silurian age is worked in the County Wicklow, at the Ballymurtagh and Cronebane mines; in the former mine, the lode to a depth of 16 fathoms is found rich in ore, after which it passes into the ordinary pyrites of the neighbourhood. This lode was first wrought about the year 1856. In Cronebane mine the ore is found on the backs of the mineral veins near the surface, to depths varying from 8 to 25 fathoms, occurring as a "gossan" resting upon Clay-Slate and pyrites, which becomes firmer and harder in depth.

The spathic ores of iron, rich in manganese and valuable for the production of Spiegeleisen, are not found extensively in Great Britain. The greatest depository of these ores occur in Somersetshire, in the upper division of the middle Devonian rocks in the Brendon and Eisen Hills, and on Exmoor; other deposits are found in Durham and Northumberland, in the Carboniferous Limestone of Alston Moor and Weardale, and a few localities in other formations in Cornwall and Devon, especially below the lead lodes in Perranzabula, and of the Exmouth and Frank Mills mines, in Christow.

The deposits of the Brendon Hills possessing a considerable range, which have been worked from an early period, have been worked by the Ebbw Vale Iron Company. The earliest workings—the Colton pits at the eastern end of the Brendon Hills—were in a zigzag form; to the west, considerable workings—thought to be Roman—were carried on at Raleigh Cross and at Burrow mine, near Wiveliscombe; while farther west, at Florry mine, the old workings were found to have a depth of 30 feet. The lode of spathose ore which occurs in this mine is of very striking character. Fig. 228 gives an accurate representation of a section at Raleigh Cross. *a a* show the enclosing walls, which are Devonian slate, and the central portion is a fragment of the same rock completely surrounded with the spathose ore *b*. This must evidently have been a fragment splintered of which the iron ore was being deposited. Farther to the west, explorations show the course of the deposits, which have been traced to Exmoor, where several lodes have been from time to time worked.

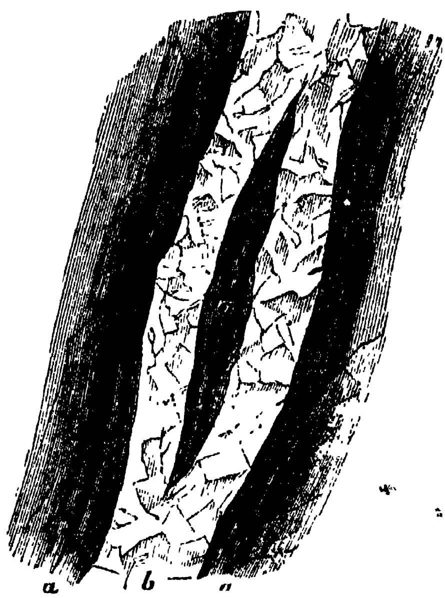

Fig. 228.—Brendon Hills.

To the Perran iron lode, occurring in the Devonian rocks, Mr. W. J. Henwood * called attention nearly half a century since, referring to it as a large vein bearing south-east and north-west, and dipping south 50°. The lode is seen on the northern coast of Cornwall at Perran, where it attains a width of 100 feet, and it extends to Mount and Trebisken. He

* "Transactions of the Geological Society of Cornwall," vol. v.

says: "At the eastern extremity of Ligger Bay is a large vein bearing south-east and north-west, dipping south 50°. It contains hæmatite, specular and earthy brown iron ore, quartz, and slate." As this lode is first seen in the Perran cliffs it is divided by a "horse" of Killas: it has been traced to Deer Park mine, which is at a distance of four miles. At this mine it appears to suffer some disturbance. It takes a direction at first directly east, and afterwards some degrees north of east. The lode is said to have been traced as far as Grampound, but this is problematic; certainly no iron ore of any value has been raised beyond the Deer Park mine. The Perran lode has been worked for about twenty years, and it is said that 200,000 tons of ore have been taken out and sold.*

At the cliff, which is nearly 200 feet high, considerable quantities of brown hæmatite have been raised. An old adit—the date of which is not known—was extended in 1871-72, and widened so as to allow of tram waggons working on an inclined plane. A shaft was sunk inland for ventilating the workings, which are, at this point, extensive. The lead lodes from a neighbouring mine, known as Wheal Golden, cross the iron lode, and fine stones of lead ore have been broken out of it.

Another shaft, Borlase's, has been sunk 15 fathoms, and a level driven to meet a large excavation on the south branch of the lode, known as the "Big Iron Pit." This portion of the sett, now known as the Gravel Hill mine, was formerly called the Penhall iron mine.

To the eastward of Gravel Hill, the Halwyn sett, which is bounded by the Mount mine, comes in. The iron ore is here raised from a depth of rather more than 20 fathoms. Treamble is still farther east, where brown hæmatite and spathose iron ores have been extensively worked. Each of the Treamble quarries are crossed by a promising lode of argentiferous galena, and some lead ore has been raised from these lodes within the Great Retallack sett. At Great Retallack mine the lode is several fathoms wide. It has been found to contain much iron ore to a depth of 40 fathoms. Zinc ore was found in the lode for the first 25 fathoms, and at a greater depth the blende increased, and for some time 500 tons per month were sold.

To the east of Great Retallack, is the Duchy mine, where workings on the lead and copper lodes were carried to a depth of 50 fathoms, and on the iron lode to between 20 and 30 fathoms. The Peru lode is only a few inches wide, but it gave silver lead of great richness, some parcels containing as much as 2,000 ounces of silver per ton of ore. Some of this silver was in visible fibres of metallic silver. The author possesses a small mass of lead ore from the neighbouring Mount mine, which is hollow, and completely filled with fine threads of metallic silver. Mr. W. J. Henwood † says: "At Trebisken Green a lode, oblique in direction to the large iron vein so well known in the same neighbourhood, affords irregular masses of rich ore. This for the most part is galena, which sometimes contained no more than 0·000153, but in some cases it has yielded as much as 0·091922 to 0·104040, and even 0·122584 its weight of silver. Portions of the lode have, however, produced 0·107100 their

* "The Great Perran Iron Lode." By J. H. Collins, F.G.S. ("Report of the Miners' Association of Cornwall and Devon for 1873.")

† "Account Books of the Mine," quoted by Mr. W. Jory Henwood. ("Transactions of the Royal Geological Society of Cornwall," vol. viii. p. 121.)

weight of metal from vitreous silver ore and native silver unmixed with lead. The ore sold from Trebisken Green mine has been—

	Quantity. T. c. qr. lb.	Price per Ton. £ s. d.	Amount. £ s. d.
1859. Sept. 14	1 14 2 0	95 10 6	164 15 6
,, Sept. 26	0 2 0 0	74 3 4	7 3 4
1860. Mar. 13	0 1 3 16	435 10 0	41 4
,,	0 14 3 19	135 0 0	100 14 1
,, ,,	0 4 3 11	7 10 0	1 16 4 (*Slimes*)
,, Aug. 14	1 9 0 12	333 7 6	485 3 0
	2 19 0 1	97 0 0	286 3 10
	7 6 1 3		£1087 5 11 total value.

Captain Nicholas Bryant states that from the Trebellen lode parcels of ore were sold for £700 per ton (*Collins*).

Mr. J. Carne stated that about 1788 the first discovery of silver ore was made "in a mine in the parish of Perranzabula, which was in consequence dignified with the name of Mexico." Mr. W. W. Smyth says: "This silver-bearing vein crosses through the iron lode in the Treamble workings, and does not appear to have been made out or followed up on the south of them. . . . . At the present time (1881) two north and south veins coming in from the north are to be seen in the Duchy mine, having a very pronounced dip to the eastward, distinctly cutting through the iron lode, promising in appearance, but disappointing so far in their productiveness."

Cellular brown hæmatite is raised in considerable quantity from the western boundary of the Duchy sett. Much of the ore contains kernels of white carbonate of iron, and water which is quite clear and tasteless.

At 20 fathoms from the surface, east of the shaft known as Vallance's shaft, is a very hot end. In this end the air is very bad, it being quite impossible to keep a candle burning in it. A thermometer has indicated the temperature of this end as 124° Fah. This high temperature is due to the oxidation of a large mass of iron pyrites.

It is a remarkable fact that the great masses of iron ore in the Perran lode occur just where it is crossed by the lead lodes of the district. The Wheal Golden lodes cross at the cliff, where the lode is 100 feet wide, the Trebisken and Trebellen lodes in Mount mine, the Great Retallack lodes in Treamble, the Duchy Peru and Wheal Hope lodes, the Shepherds' lode, and others. The effect of these junctions is also seen in the lead lodes, which all contain large proportions of silver near their junctions. All indications appear to point to the probability that, in depth, the iron lode will pass into copper, galena, or blende.

A few other localities in which lodes of iron occur in Cornwall remain to be referred to. At Boscarne, west of Bodmin, a lode, partly wrought, has a run of 750 fathoms, with an average width of 1 fathom. At Nantallon, south of Boscarne, three lodes occur, two having a run of 1,750 fathoms, and the third 2,200 fathoms; the width of one of the lodes being 3 feet and the remaining two 6 feet each. Again, to the south and west of Bodmin, at Tremoor, two lodes, extending 2,000 yards and averaging 3 feet wide, occur. Other lodes at Coldvreath, with a north and south direction extending some 890 fathoms, have been proved having a width of about 1 fathom.

In Cumberland and Lancashire the chambers or caverns in the Limestone are of considerable extent, the thickness of the deposits varying from 30 to 100 feet in depth and even more; the forms of the deposit are very irregular, and it has been observed that their general direction corresponds with the magnetic meridian. The deposits at Parkside exhibit a section in greatest depth of 70 feet, the area extending over about 60 acres. At Millom the deposits have an area of nearly 1,000 acres. Mr. J. D. Kendal* divides the deposits in the Carboniferous Limestone into four kinds: 1st, bed-like deposits; 2nd, vein-like; 3rd, dish-like; and 4th, irregular-shaped deposits. In Furness they may be separated into three kinds: 1st, vein-like; 2nd, dish-like; and 3rd, irregular-shaped; and remarking that, as far as he is aware, there is not a single "bed-like" deposit in the Furness district, unless the small flats from the Lindal Moor and Stank veins be considered as such. In the Furness district some of the most important deposits occur. That at Lindal Moor has been worked about 1,000 yards in length in a direction north 25° west, and south 25° east, its breadth being very variable, ranging from a few inches to 30 yards. Again, at the Stank mines the ore occurs in a similar mass, the direction of it tending to about 25° north-west and south-east. This has been worked for a length of about 600 yards and for a depth of about 30 yards without reaching the bottom. The width varies from a few inches to 25 yards, including the masses of Limestone which are imbedded in the ore. Most of the ore deposits are of the dish-like form. In their simplest outline they are roughly-like filled irregular basins just below the drift. While at times it is observed that deposits of this kind are so long as compared with their breadth that they seem almost like veins, these "dish-like" deposits, so common in Furness, are rarely met with in the Whitehaven district.

Of the irregular-shaped deposits, the most important in Furness is at Askam, its total area being about 16 acres; its length in a north and south direction would be about 260 yards, and from east to west about 300 yards. It is overlaid by about 16 fathoms of drift, and on the dip side of the deposit where it has a rock roof the ore extends to a depth of 40 fathoms. It is remarked of this deposit, notwithstanding its irregular form, that it has the same dip as the Limestone, extending to a less depth on the rise side where it comes up to the drift than on the dip side where it has a rock roof. This appears to be a common feature of the deposits both in Furness and Whitehaven.

The "kidney" and "puddler's" ores, extensively mined in the neighbourhood of Whitehaven, in Cumberland, and Ulverston, in Lancashire, are by far the most important ores raised in the United Kingdom, the kidney ore, which occurs in the harder varieties of hæmatite, deriving its name from the circumstance of its appearance presenting a finely-lobed surface. The general character of the Whitehaven hæmâtite at Cleator Moor is as follows:† "compact red hæmatite, easily scratched by a file; lustre, earthy; colour, purplish grey; streak, bright red; fracture, uneven; containing

* Mr. J. D. Kendal, "On the Hæmatite Deposits of Furness," read before the "North of England Institution of Mining and Mechanical Engineers," vol. xxxi. 1882.

† "Iron Ores of Great Britain," Part I. p. 61, published in "Memoirs of the Geological Survey of the United Kingdom."

cavities lined with crystals of specular iron, and containing in some cases quartz." The amount of metallic iron in two samples of Cleator Moor ore being 63·25 per cent. and 66·60 per cent. The total output of the Whitehaven mines in 1881 amounted to 1,615,635 tons, of the value of £1,186,709.

The hæmatite of Lancashire in the Furness district is divided by Mr. J. D. Kendal, in his paper on these deposits,* into three classes, the first class being *hard compact blue purple ore*, in which there are numerous loughs, lined with kidney-like concretions and spar, such as occur in the Whitehaven deposits. This variety is found in the northern end of the Lindal Moor deposit, in the Stank deposit, and in part of the Askam deposit. Analyses of these ores give of metallic iron 55·03 per cent., 58·10 per cent., and 65·98 per cent. respectively. The second class consist of a *dull reddish purple ore*, found at the southern end of the Lindal Moor deposit, in part of the Stank

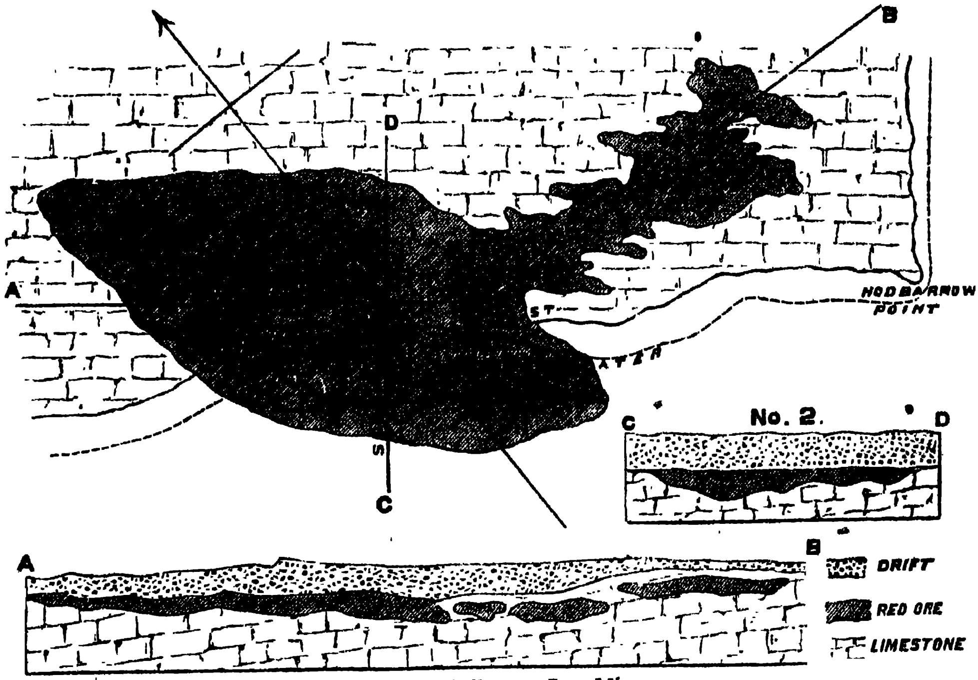

Fig. 229.—Hodbarrow Iron Mine.

deposit, and elsewhere, the softest being known as puddling ore, and giving of metallic iron from 54·06 per cent. to 60·55 per cent. The third class is distinguished as *soft dark ore*, and is the most abundant ore in the district of Furness, being that which is mainly found in dish-like deposits, the analyses of four samples of the soft ores giving respectively of metallic iron 42·43 per cent., 48·81 per cent., 52·75 per cent., and 59·13 per cent. It may be observed that 45 per cent. represents the average of metallic iron in the poorer ores of Furness, similar ores in the Whitehaven district giving 50 per cent. The total output of the Lancashire hæmatite deposit in the year 1881 amounted to 1,180,836 tons, of the value of £755,827.

A few additional words are necessary on the remarkable deposit at Hodbarrow, near Holborn Hill, which is shown in plan and sections in Fig. 229.

* "Proceedings of the North of England Institution of Mining and Mechanical Engineers," vol. xxxi. 1882.

The two sections, A B and C D, given, one crossing the other at right angles, show that the depth of these deposits is not great. The deposit has flowed in from the east, and regularly filled the subterranean pond previously prepared to receive it. This immense deposit extends from above the line of high water in the Duddon to beyond the line of the coast under the bed of the river. The production of iron ore from this mine for the last ten years has been as follows:—

Year.	Tons.	Value.			Year.	Tons.	Value.		
1873	203,791	£251,738	13	0	1878	274,962	£185,599	7	6
1874	201,663	252,078	15	0	1879	293,637	161,500	0	0
1875	202,817	254,162	10	0	1880	348,194	240,236	0	0
1876	271,098	189,768	12	0	1881	358,621	251,034	0	0
1877	277,195	202,645	0	0	1882	453,823	340,142	0	0

The workings of such immense masses of iron ore are necessarily attended with difficulties. In the hardest ore they are not unfrequently 40 feet wide, and sometimes they extend to 70 feet; as a rule, however, about 16 feet is the width fixed by experience as the most suitable. The height is generally from 10 to 12 feet, but often it extends to 20 or 30 feet.

In the Parkside mines, Whitehaven, a working 70 feet in height also claims a short notice. Timber is not generally employed, the Limestone rock and the iron ore being generally sufficiently coherent to support itself. When the height of the iron ore is considerable and the deposit irregular, the rise is completely laid open by drifts, driven up the surrounding Limestone, or "pinnell," as it is locally called. Sometimes, on account of the soft and incoherent nature of the ore, much advance cannot be made without the use of considerable quantities of timber. When all the ore is obtained that can be got out with safety, great caution is required in removing the pillars which have been left to support the roof. On the removal of these the ore above and around, unable to support the incumbent mass, subsides, and an end is brought to that portion of the mine. The crushing of a mass of ore with the Limestone and drift above it will be best understood by Fig. 230, which is an exact representation of such a crush in one of the Whitehaven mines:—

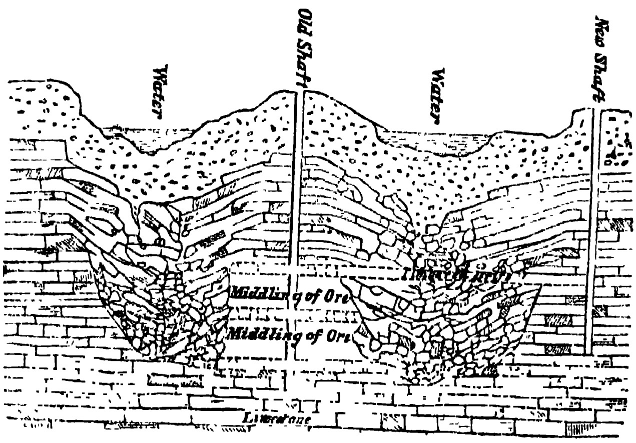

Fig. 230.—Crush in Iron Mine.

These remarkable deposits of iron ore have been, without doubt, derived

from the older rocks—in all probability from the Old Red Sandstone, which has been entirely removed from the district north of the Whitehaven and the Furness iron districts. The Old Red Sandstone, always rich in iron, would, in the process of denudation, furnish all that was required. The process by which this was effected demands more careful consideration than it has hitherto received. When the Sandstone, impregnated with the peroxide of iron, was being removed by denudation, the waters by which this was effected were highly charged with carbonic acid derived from the vast masses of vegetable matter which were undergoing decomposition. This vegetable matter in decomposing reduced the peroxide of iron to a state of protoxide, which would be dissolved as a supercarbonate of the protoxide of iron in the highly carbonised water. By a previous action this carbonised water, in flowing through the Limestone, dissolved out large quantities of the rock, and thus formed the caverns and cavities into which the peroxide of iron was eventually to be deposited. In the Coal Measures adjoining the Parkside mine, Whitehaven, a thin stratum of argillaceous iron ore was discovered spreading over a coal bed to some extent. So long as an abundance of vegetable matter was present the peroxidation was prevented, and the iron mingled with clay went down as a protoxide or formed a bed of clay-band ironstone. Escaping from the mass of decaying vegetable matter in which this carbonate of protoxide was formed, the atmosphere was constantly producing films of peroxide on the surface, and iron in its highest degree of oxidation. Red hæmatite was precipitated in the caverns, and water-worn fissures prepared to receive it.

The accompanying woodcut (Fig. 231) represents an illustrative section

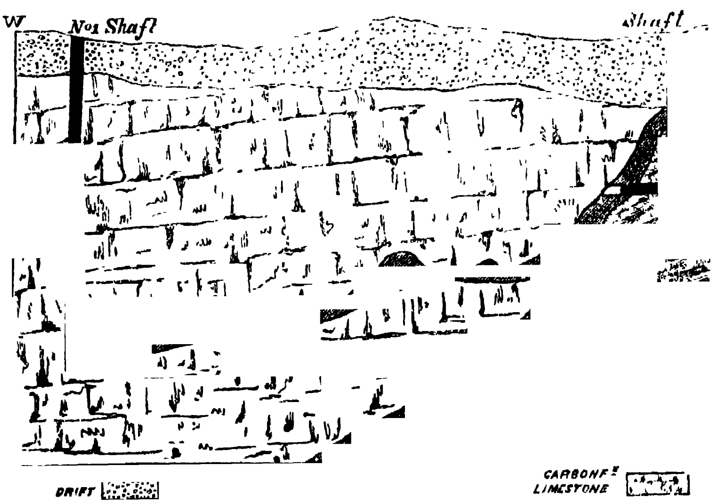

Fig. 231.—Egremont Mine.

of the *Egremont mine,* Whitehaven. It will be seen that a channel has been in the first instance formed in the Carboniferous Limestone, which has subsequently been completely filled in with red hæmatite iron ore, in the manner described.

The beds of ironstone in the Lower Lias formation in North Lincolnshire

extend over a large area with a varying thickness. The ore is obtained by open quarry workings as in Northamptonshire, the "over-burden," or soil covering the ironstone, being inconsiderable in depth, is easily and inexpensively removed, not requiring skilled labour.

The area of greatest development of ironstone in the Middle Lias is disclosed in the Cleveland Hills, in the North Riding of Yorkshire, at the top of the Middle Lias, or "Marlston Rock." At Eston the bed of ironstone attains its greatest thickness, varying from 12 to 17 feet. This seam is also known as the "Pecten Bed," from the fact of the occurrence throughout its area of the well-known fossil shell (*Pecten æquivalvis*).

At Upleatham the main seam previously referred to has a thickness of 13 feet, exhibiting a varied character, in which the one general structure is maintained. At Gisborough, at the Challoner mines, the main seam has a thickness of from 12 to 13 feet; at the Normanby mines it does not exceed 11 feet; while at the Loftus mines, near Loftus, it does not exceed 9 feet 6 inches. Towards the south of the district the seam is found thinning out until Felix Kirk is reached, a district a few miles north-east of Thirsk, where the same bed is found to exist in a section of 6 or 7 inches, with shaly partings of 3 feet.

The beds of ironstone in the Middle Lias in Oxfordshire vary from 2 to 10 and even 12 feet in thickness, and of a very compact character, often presenting the appearance of a solid rock. The stone has been worked for many years at Adderbury, and some has been raised at Fawler and a few other localities in the county. The ore in this area was first worked about the year 1859, and at the present time the deposits at Adderbury are the only deposits worked in Oxfordshire.

The iron ore deposits in the Lower Oolite of the Northamptonshire area have a varying thickness, from about 4 or 5 feet to upwards of 20 feet, with an equally varying "over-burden." In the neighbourhood of Duston and Gayton, to the west of Northampton, the ironstone varies from 10 to 12 and 16 feet thick with a covering of soil, &c., of about 5 feet. In Wellingborough the ironstone varies from 12 to 16 feet in thickness; between Kettering and Thrapston some good sections are met with at Islip, Woodford, Cranford, and Kettering, where the ironstone exceeds 20 feet, and in one or two places it was formerly mined by underground workings. The ironstone now in course of development is all open quarry workings, and an acre of ironstone in the Wellingborough district is estimated to yield upwards of 10,000 tons of ironstone.

The beds of iron ore occurring in a subdivision of the Middle Oolite, known as the "*coral rag*," are limited to a few localities and of inconsiderable extent, that at Westbury being the most important, where it has a thickness of 15 feet, and it has been traced from the Westbury Iron Works, where the ore is smelted, up through Steeple Ashton into Oxfordshire, by Rowde, near Devizes, and the high ground south of Chippenham.

The ferruginous ores obtained from the Lower Cretaceous strata are of comparatively low percentage, and are therefore not worked. The deposits at Seend in Wiltshire occur in the Lower Greensand, where they have an area exceeding 150 acres, the over-burden in places not exceeding 1 or 2 feet. These

deposits have been for some years undisturbed. In Buckinghamshire, at Leighton Buzzard and Linslade, ironstone in the Lower Greensand is found, not in a continuous bed, but in nodules large, massive, and of a brown ochreous character, often hollow, and containing loose white sand. Another deposit of similar age occurs at Tealby, in Lincolnshire, where the bed has a thickness of 6½ feet, made up of Oolitic grains; this ore is regarded as a useful ironstone in admixture with other ores.

The brown and aluminous rich ores of the County Antrim consists of several beds, the uppermost or Pisolitic bed having a thickness varying from a few inches to 2 and 3 feet, and consisting of a soft brown or reddish-brown ferruginous ochre, in which are imbedded small dark grey irregular pieces of harder ore. Beneath the Pisolitic bed is a seam composed of a yellowish-red ferruginous ochre, containing a number of concretionary nodules of basalt called "Bole," with a varying thickness of from 5 to 10 feet. The lowest bed, known as "Lithomarge," and consisting of a variegated soft rock of a prevailing blue slaty colour, contains, like the bole, concretionary nodules of basalt; this bed at times attains a thickness of nearly 80 feet.

The Character of the Various Ores of Iron.—The iron ores obtained from the rocks of Great Britain may be regarded as of two varieties, oxides and carbonates; the former including magnetite, or magnetic iron ore, hæmatite, of which there are several varieties known to the iron smelter, and limnite, or brown iron ore.

Of the *magnetic iron ores*, the chief deposits wrought in Great Britain occur in Rosedale, in the North Riding of Yorkshire. The year of greatest production was 1873, when 560,668 tons of ore were raised, of the value of £168,200. Since that date a great falling off appears, the output in the year 1880 amounting to 6,079 tons, since which date operations have been suspended. The amount of metallic iron in these ores, according to analysis by Messrs. Crowder and Pattinson, of Newcastle-upon-Tyne, gives from 45·43 per cent. to 49·20 per cent. The Rosedale ore was chiefly smelted at the works of the Rosedale and Ferryhill Iron Works, and to some extent at other works.

Hæmatite.—The varieties may be generally summarised as specular iron ore, micaceous iron ore, kidney ore, and puddler's ore, the last named being much used for lining the hearths of puddling furnaces. The first named is not found abundantly in the rocks of Great Britain. The *micaceous* deposits of iron ore worked are inconsiderable; the deposit at Hennock, in South Devon, where the ore occurs in a close-grained porphyritic Granite, being associated with quartz, schorl-clay, and hornblende, has not been recently worked.

Brown Iron Ores, or Limnite.—There are several varieties of this ore, described generally as being of a brown colour, sometimes yellowish-brown, with a rather dull sub-metallic or silky lustre, often with a shiny black coating. The Dean Forest ores of Gloucestershire are of three varieties: one, a compact, close-grained, black ore, locally known as "Brush ore," giving 63·50 per cent. of metallic iron; the second, a cellular or spongy variety, often tough, also black and very rich; and the third, a broken earthy-looking ore, less rich in metallic iron, but used extensively in admix-

ture with the other varieties by the iron smelter. Other analyses of the Forest ores give 63·04 per cent. of metallic iron, and a more earthy variety, known as "Smith ore," 62·86 per cent.; "Grey ore," 34·46 per cent.; and "Brandy Brush," 22·93 per cent.

In Cornwall, the brown hæmatite of Restormel consists principally of a crystallised variety known as Göthite, occurring in fibrous and mammillated aggregations, and also in long prismatic crystals. These ores, examined by Mr. J. Pattinson, of Newcastle-on-Tyne, are found to contain metallic iron varying from 31·90 to 55 per cent.; the average, however, may be taken as 45 per cent.: the presence of manganese in considerable proportion rendering them of much value for the manufacture of iron and steel. In the adjoining county of Devonshire the ore raised at Smallacombe, near Ilsington, contains 50·44 per cent. of metallic iron, the ores of Torbay, near Brixham, yielding from 44·56 per cent. to 63 per cent., and even more.

The brown hæmatite wrought in the Silurian rocks at the Ballymurtagh mine, in the County Wicklow, gives of metallic iron from 46 to 50 per cent. The year of greatest production was 1864, when 25,164 tons were brought to bank, of the value of £7,744; the output in 1881 being but 1,433 tons, of the value of £430.

Another deposit of brown hæmatite to be noticed is that worked at Westbury, Wiltshire, in the Coral Rag; of this ore two kinds are recognised, brown and green. The general character of the ore is of a dark ochreous kind, presenting a greenish appearance when freshly broken, the brown ore giving 41·99 per cent. and the green ore 38 per cent. of metallic iron. This deposit was first worked about the year 1858, when 5,719 tons were raised; the year of greatest production being 1871, when the output amounted to 109,151 tons; while in 1881 the production was but 39,222 tons, of the value of £7,844.

In *Northamptonshire* and *Lincolnshire*, the brown ores of iron, furnishing nearly 15 per cent. of the ore reduced in the blast furnaces of the kingdom, produced in 1881 in the first-named county 1,270,544 tons, of the value of £176,426; Lincolnshire producing in the same year 1,021,506 tons, of the value of £154,600. Numerous analyses of the Northamptonshire ores give the average yield of metallic iron of these ores as about 40 per cent. This is exceeded in some localities; for example, Brixworth ore gives 43 per cent., Towcester ore 46·67 per cent., and Cogenhoe ore 48 per cent. of metallic iron.

The brown Oolitic ores of *Lincolnshire* which were examined by Mr. Charles Tookey, of the Royal School of Mines, from the bed at Brigg, near Frodingham, gave an average of 40·67 per cent. of metallic iron; other samples from the various bands of the main bed, yielding, according to other results, from 28·80 per cent. to 33 per cent., and as much as 44·25 per cent., some parts of the deposits being highly manganiferous.

The ores of Oxfordshire, of brown Oolitic variety, are inconsiderable, amounting in 1881 to 8,614 tons, of the value of £1,507. The ore raised at Adderbury—a calcareous variety—gives from 36 to 37 per cent. of metallic iron.

The iron ores—which are rich in manganese, rendering them of great importance in the manufacture of pig-iron, especially when it is to be con-

verted into steel—have been analysed by Mr. John Spiller, of the Royal School of Mines, giving 34·65 per cent. of metallic iron and 9·78 per cent. of manganese. The spathose ore of Weardale, examined by Mr. A. Dick—described as "easily scratched by a file; lustre, semi-vitreous; colour, yellowish grey; streak, white; fracture, crystalline"—yielded on analysis, 38·56 per cent. of metallic iron, the protoxide of manganese amounting to 2·42 per cent. The spathose ore raised at Frank Mills and South Exmouth mines, examined by the late Dr. Noad, contains 38·26 per cent. of metallic iron in the raw ore, increased to 54·70 per cent. in the calcined state.

Argillaceous Carbonates of Iron.—These ores, raised extensively in the Cleveland Hills of the North Riding of Yorkshire, are well described in the "Memoirs of the Geological Survey."* The memoir relating to iron ores being out of print, it will be convenient to give a description of the ore raised at Eston, in Cleveland, in the mines of Sir Joseph Pease and partners. It is said to be: "Chiefly a carbonate of the protoxide of iron; lustre, earthy; colour, greenish grey; streak, similar; fracture, uneven, showing now and then small cavities, some of which are filled with carbonate of lime. Throughout the ore are diffused irregularly a multitude of small oolitic concretions, together with small pieces of an earthy substance resembling the ore, but lighter in colour." The amount of metallic iron contained in this ore amounts to 33·62 per cent. The average amount of iron contained in the ores of Cleveland may be taken at about 30 per cent., the calcined ore yielding 40·81 per cent. of metallic iron. The Cleveland ores vary in their contents of metallic iron from 28·60 to 35·47 per cent. at the South Bank Works, the ore raised at Upleatham yielding 31·97 per cent. An early return in 1854 gives 650,000 tons, increased to 1,471,319 tons in 1860, and 4,072,888 tons in 1870, the year of greatest production being 1881, when the output of 27 mines in operation amounted to 6,538,471 tons, of the value of £1,062,501, the average value of the ore at the mines being estimated at from 3s. to 3s. 6d. per ton.

The brown aluminous ores of Antrim alone remain to be referred to. Those of Glenarm and Carnlough giving, the first named, 35·96 per cent. of metallic iron and 30 per cent. of alumina, as determined by Mr. C. A. Heywood, of Whitehaven; the Carnlough ores, examined by Mr. Tosh, yielding 22·47 and 17·89 per cent., the respective proportion of alumina varying from 33·69 to 34·55 per cent. Another aluminous ore raised at the Glenariff mines, examined by Mr. Jones, of Wolverhampton, a second-class ore, gives 25·15 per cent. of iron and 36·50 per cent. of alumina; the best aluminous ore obtained from the same mine yielding 47·40 per cent. of metallic iron and 10·19 per cent. of alumina.

The Bauxite deposits of the Irish Hill and Straid mines, near Ballymena, examined by Mr. John Pattinson, gave of alumina 53·83 per cent., 52·00 per cent., and 46·13 per cent.

The production of these aluminous ores in Ireland in the year 1857 amounted to 3,000 tons, increased in 1867 to 42,016 tons, of the value of £10,641; and in 1877 to 155,382 tons, of the value of £85,427; and in 1881 to 198,429 tons, of the value of £85,495.

* "Iron Ores of Great Britain," part i. p. 95.

In concluding this notice of the iron ores of the United Kingdom—not in the Coal Measures—we give the total production of the several varieties in the years 1881 and 1882:—

Counties, &c.	Variety of Ore.	1881. Quantities.	1882. Quantities.
		Tons.	Tons.
Cornwall	Red and brown hæmatite	7,460	5,740
Devonshire	Magnetic brown and red	11,198	11,481
Somersetshire	Spathose and brown hæmatite	29,883	36,067
Gloucestershire	Brown hæmatite	90,497	80,672
Wiltshire	Brown oolitic	39,222	99,176
Oxfordshire and Rutland	Brown oolitic	8,614	12,753
Northamptonshire	Brown oolitic	1,270,545	1,333,085
Leicestershire	Brown oolitic	99,599	267,802
Lincolnshire	Brown oolitic	1,021,507	1,190,564
Staffordshire, North	Calcareous hæmatite	30,721	—
Lancashire	Red hæmatite	1,189,836	1,408,693
Cumberland	Red hæmatite	1,615,635	1,725,478
Yorkshire (Cleveland)	Brown oolitic	6,538,471	6,326,314
Northumberland and Durham	Spathose and silicious hæmatite	70,771	83,726
North Wales	Red hæmatite	2,155	2,471
South Wales and Monmouthshire	Brown hæmatite	81,372	77,162
Isle of Man	Brown hæmatite	120	—
Ireland	Aluminous	199,863	189,724
Scotland	Brown hæmatite	5,235	1,907
Total production in the years 1881 and 1882.		12,312,711	12,852,824

The total value of the ore in 1881 amounting to £3,634,391. In the same year the imports of foreign ores of iron were 2,450,698 tons, of the value of £2,349,411.

It appears necessary, to render the description of the iron ores of the United Kingdom complete, to add the returns, as given by the Inspector of Coal Mines, of the argillaceous iron ores obtained from the Coal Measures for the last five years:—

1878	10,306,560 tons	1881	11,858,766 tons
1879	11,871,745 „	1882	11,505,447 „
1880	11,664,726 „		

The actual quantity of ore used in our blast furnaces in 1882 being 26,808,969 tons.

BRITISH MINING.

BOOK IV.

THE FUTURE PROSPECTS OF BRITISH MINING.

CONTENTS OF BOOK IV.

BRITISH MINING.

BOOK IV.

THE FUTURE PROSPECTS OF BRITISH MINING.

CHAPTER I.

SUMMARY.—EXAMINATION OF THE PROBABLE EXHAUSTION OF METALLIFEROUS MINERALS.

Tin.—Until 1845, in which year the author was appointed "Keeper of Mining Records," no successful effort had been attempted to obtain reliable returns of the quantities of metalliferous ores obtained annually from the mines of the United Kingdom.

Several estimates,—many of them made with a considerable amount of care,—had been from time to time published, giving the production, within a given period, of the mines of certain defined districts, or producing some special mineral. These were derived from very varied sources of information, many of them of uncertain value, and it was not possible, therefore, to make an estimate of the real condition of any set of mines, upon which reliance could be placed.

The chief purposes for which the Mining Record Office was established, will be seen from the following Minute of Resolutions, passed by the Council of the British Association at the meeting in Newcastle-upon-Tyne, August 25th, 1838. It appears important, as a matter of history, to give permanence to this; showing, as it does, that a very few years effects a change in the opinions of men, on questions which were at one time considered to be settled as of vital importance, and alters arrangements which, when made, contemplated the permanent preservation of records of the progress of the most important industry of the United Kingdom:—

1st. "That it is the opinion of this meeting that, with a view to prevent the loss of life and of property which will inevitably ensue from the want of accurate Mining Records, it is a matter of national importance that a depository should be established for the collection and preservation of such Mining Records of subterranean operations in collieries and other mining districts.

2nd. "That a committee be appointed to draw up a Memorial, and to communicate with the Government in the name of the British Association respecting the most effectual method of carrying the above resolution into effect.

3rd. "That the committee consist of the following gentlemen, with power to add to their number:—

The Right Hon. the Marquis of Northampton.
Sir Charles Lemon, Bart., M.P.
Sir Philip G. Egerton, Bart.
John Vivian, Esq.

Davies G. Gilbert, Esq.
J. S. Enys, Esq.
W. L. Dillwyn, Esq.
Charles Lyell, Esq.
The President for the time being of the Geological Society of London.
The Professors of Geology in the Universities of Oxford, Cambridge, London, and Durham.
H. T. de la Beche, Esq.
John Taylor, Esq.
John Buddle, Esq.
Thomas Sopwith, Esq."

In pursuance of the above resolutions a meeting was held at the offices of Mr. Sopwith, in the Roya Arcade, Newcastle, on Monday, August 27th. Present—

Sir CHALES LEMON, Bart., in the chair. The Rev. Dr. Buckland, the Rev. Professor Sedgwick, Professor Phillips, Professor Johnson, John Buddle, Thomas Sopwith, and Richard Griffiths, Esquires.

It was proposed by Dr. Buckland and seconded by Mr. Sopwith—

"That Richard Griffith, of Dublin; Robert Bald, of Edinburgh; and J. Barker, of Bakewell, Esquires, be added to this Committee."

It was proposed by Dr. Buckland and seconded by Mr. Buddle—"The Secretaries be appointed as follows:—

John Taylor, Esq., F.R.S., F.G.S., General Secretary.
Thomas Sopwith, Esq., F.G.S., Secretary of North of England.
Richard Griffith, Esq., C.E., F.G.S., Secretary for Ireland.
Robert Bald, C.E., F.R.G.S., Secretary for Scotland."

Dr. Buckland having read the resolutions passed by the Council of the British Association, the following Memorial was drawn up, and having been approved, Sir Charles Lemon undertook to transmit it to the Chancellor of the Exchequer, which has accordingly been done, and the subject is now under consideration.

Copy of the Memorial of the MINING RECORDS Committee.

"To the Right Honourable the Lords of Her Majesty's Treasury, &c.

"The Memorial of the COMMITTEE for the PRESERVATION of MINING RECORDS appointed by the BRITISH ASSOCIATION for the PROMOTION of SCIENCE, assembled at Newcastle, August 25th, 1838—

"Humbly sheweth :

"That whereas it has been made apparent to your Memorialists that great loss of life and destruction of property have resulted from the imperfect preservation of Mining Records; and whereas still greater losses will inevitably ensue unless advantage be taken of the experience of living individuals, who are willing to place in any public depository that may be provided, copies of the numerous mining documents now in their possession;

"And whereas the preservation and economical use of mineral produce, and especially of coal, are of great importance, not only to the proprietors of mines, but to the nation at large:

"Your Memorialists feel it to be their duty, respectfully and earnestly, to call your Lordships' attention to the *expediency of establishing, as soon as possible, a National Depository for the preservation of documents recording the Mining Operations of the United Kingdom.*

"That the experience of the neighbourhood of Newcastle, within the personal knowledge of several of your Memorialists, affords appalling examples of the loss of life, and waste of highly valuable Mineral Property, which would never have occurred had such documents been preserved as it is now the object of your Memorialists to collect. As in the lapse of time mining operations become of necessity more complicated and dangerous, the risk of the recurrence of similar catastrophes will be continually increasing. It appears to your Memorialists that the only sure and effectual means of preventing those deplorable results is the establishment of such a public office as has already been alluded to.

"The practicability of carrying out the above measures has been shown by what has recently been done under the direction of the Board of Woods and Forests, in the case of the coal mines in the Forest of Dean, and by the documents relating to the coal mines of Newcastle, which have been deposited by Mr. Buddle in the archives of the Natural History of Newcastle. It is within the knowledge of your Memorialists that an immense number of similar documents are in the possession of individuals who are now willing to place copies of them in any public depository under the control of Government.

"Your Memorialists therefore humbly pray that your Lordships will be pleased to take the premises into your consideration.

"(Signed) CHARLES LEMON,
Chairman."

The result of this was that the Lords of the Treasury adopted the recommendations, and on the 29th September, 1840, the Mining Record Office was established under the department of Woods, then presided over by Lord Duncannon. It was placed in charge of Mr. (afterwards Sir Henry) de la Beche, the Director-General of the Geological Survey, and of the Museum of Economic Geology: Mr. Thomas Jordan being appointed the first Keeper of Mining Records, which appointment he held until April, 1845. The author succeeded Mr. Thomas Jordan, entering on the duties of his office on the 19th April, 1845.

Interpreting the words of the above Memorial to signify not only the preservation of plans, &c., of mine workings, but the returns of produce from our metal mines and collieries, the author was induced to make the experiment of soliciting from the proprietors accurate returns thereof. In 1847 the first attempts to collect Mineral Statistics were so far organised, that a series of tables giving the produce of our copper and lead mines for several years * were issued, and in 1853 "Statistics of the Produce of Copper, Tin, Lead, and Silver from the Mines of the United Kingdom from 1848 to 1852 inclusive" † was published.

In that year the Treasury appointed a committee to inquire into the working of the several departments then under the direction of Mr. Henry de la Bęche. That committee reported most favourably on the work done in the Mining Record Office, and recommended that it should be placed "*on a more efficient footing.*" The Treasury acted on that recommendation. The Keeper of Mining Records was placed in a position to extend his inquiries, and, since that date, "The Mineral Statistics of the United Kingdom" has been regularly published each year until 1882, when the Mining Record Office was abolished, and the business of collecting the "Mineral Statistics" transferred to the Inspectors of Collieries and Metal Mines—the compilation and publication being placed in charge of the Home Office.

This statement has been made for the especial purpose of showing the extreme degree of uncertainty which prevailed in respect of the annual value of the mineral productions, drawn from the rocks of the British Islands, previously to the organization of the system referred to. The question of the importance of preserving records of all our subterranean works is admitted, the Mines Regulation Acts requiring that the plans and sections of all abandoned collieries and mines shall be sent to the Secretary of State for the Home Department. This excellent provision is, however, rendered seriously ineffective, by the clause regulating that those records shall be seen only "by an inspector under the Act," until ten years have elapsed from the period at which the plans were deposited.

Our present purpose is to examine, by such lights as are available—and they are very few—the extent to which the traffic in tin raised in Britain was carried on with the inhabitants of the countries on the eastern shores of the Mediterranean Sea, and thus to endeavour to make an estimate—which must be approximate only—of the total quantity of tin raised in Cornwall and that portion of Devonshire which lies west of Exeter, from the commencement of mining. In the Historical Sketch it has been shown, that tin was known to Moses 1600 B.C., and, that Ezekiel mentions that metal as being, 600 years B.C., an article of trade with the merchants of Tarshish, and, earlier still, that Homer tells us it was used in the manufacture of a corslet. Herodotus, 440 B.C., mentions the metal tin, but he says he knows not the islands from which it was obtained. Several other instances might be adduced to prove that tin was not unfamiliar to the ancient workers in metal. From whence did they obtain it? Undoubtedly tin may have been procured from the Indian Archipelago, and from the

* "Memoirs of the Geological Survey," vol. ii. part ii.
† "Records of the School of Mines."

southern promontory of India, or it may have been gathered from the rivers, or the mines, of Spain and Britain.

Assyria, it has been said, procured tin, for the manufacture of her bronzes, from India by an overland route; and, seeing that the Phœnicians were originally from that part of Asia, there is no improbability in supposing that when they founded Tyre and Sidon, they kept up some traffic with their ancient home.

This very obscure question has been examined with considerable acumen by Dr. George Smith.* He quotes the Periplus of Arrian,†—a merchant navigator of Alexandria in Egypt,—who had traded from the head of the Red Sea to the coast of Africa, around Arabia and India, and to the Island of Ceylon. Amongst his lists of imports into Egypt he names white copper,—probably a bronze,—and brass and tin, *in small quantity at a few ports only.*

An examination of all that has been written on this subject, in the earlier pages of this volume, leads to the conclusion that at least 1,200 B.C. the Phœnicians, sailing round the coasts of Spain, discovered that the metal tin might be obtained from that country. There is, also, strong evidence that they made Gadez (the modern Cadiz) a port of importance, from which they shipped this valuable product for the use of the metallurgists of Tyre. Having established a trade between Gadez, and the countries on the eastern borders of the Mediterranean Sea, these adventurous navigators began to explore the coasts of the countries to the north, and thus they discovered the "Tin Islands," of which Herodotus tells us, "It is nevertheless certain that both our tin and amber are brought from those extreme regions." The voyage of Himilco gives us, with tolerable clearness, a statement which has the appearance of truth, that the voyage from Gadez to the Tin Islands occupied at least four months. There exists evidence of a striking character, which proves that the Phœnicians (vulgarly called Jews) established themselves, in small colonies, in several parts of the western promontory. The remains of earthworks, and cyclopean walls, assure us, that the native miners endeavoured to protect their tin ground from the strangers (*Sarsens*), and there can be no doubt that the islands, spoken of by Diodorus, were the marts to which the Celtic miners of Dumnonium took their tin for sale to the Oriental merchants.

Five hundred years before the birth of Christ, there is but little doubt, that there existed a trade in the metal tin, but to what extent this was carried on we have no authority to guide us. When we reflect on the quantity of tin which would be employed in Egypt, in Phœnicia, and in Greece, in the manufacture of bronze; which alloy was employed in the construction of weapons of war and implements of industry, in casting idols for worship and ornaments for decoration, it appears that not less than 100 tons of this metal could have been exported every year from Britain alone.

* "The Cassiterides: an Inquiry into the commercial Operations of the Phœnicians in Western Europe, with particular reference to the British Tin Trade." By George Smith, LL.D.

† Under the title of "The Periplus of the Erythrean Sea." This work, which Dean Vincent translated, he attributed to A.D. 64. The learned Dean of Westminster says, in his "Commerce and Navigation of the Ancients in the Indian Ocean": "This work contains the best account of the commerce carried on from the Red Sea and Coast of Africa to the East Indies, during the time that Egypt was a province of the Roman Empire." Mr. W. D. Cooley, in his "Maritime and Inland Discovery," places considerable reliance on this work of Arrian, as showing that tin was first brought to Egypt from India, forgetting that Arrian wrote 1,600 years after tin was supposed to have been introduced.

Julius Cæsar landed in Britain fifty-five years before the birth of Christ, and the Romans held possession of these islands for three centuries and a half.* The native inhabitants of Cornwall appear to have held almost undisturbed possession of that district for all that period. The Roman remains which have been found, and which are described, were few. These probably show that some of the Romans, searching for gold, rather than for tin, established themselves in some of the mining districts of the West. It is, however, probable, as Cæsar tells us, "that the merchants who inhabited the coasts of Gaul" resorted to Britain for trade. These merchants, we may suppose, encouraged the search for tin, and established the overland route through Gaul to Marseilles. This consideration would lead us to suppose that during the period of Roman occupation as much tin was exported as previous to the commencement of the Christian era.

The Saxons gained possession of Cornwall and Devon in A.D. 947, and we are told of a ship laden with tin, sailing from Cornwall to Alexandria, being under the protection of an angel. The introduction of bells greatly increased the use of tin, and in the sixth century bells were commonly used in France and in this country. All the old bells contain a notable quantity of tin. Much of this metal was also then used for tinning iron and copper vessels. In the beginning of the thirteenth century, Venice received tin from Cornwall by way of Bruges, in Flanders, and Pisa and Genoa engaged their own vessels in this trade.

Balducci† informs us that 1,000 lbs. of tin in Cornwall was then worth 10 marks sterling, the value of the mark being equal to 4 florins. We may therefore infer, that after the departure of the Romans from Britain, to about the landing of William the Conqueror—another 500 years—there must have been a considerable increase in the produce of tin.

King John, in 1201, gave a charter to the Tinners, which was confirmed and improved by Edward I. in 1305, and in 1337 Edward III. created the Duke of Cornwall and organised more satisfactorily the Stannary Court, which originated in the days of Athelstan, about 950 A.D. From the time of King John—who is said to have expelled the Jews, who had been for some time the most industrious miners—the produce of tin fell off, and until the reign of Henry VII. everything connected with mining was in a sad state of confusion. In 1509, for the purpose of encouraging the production of tin, the use of imported tin was forbidden. The importation could never have been large, as this metal came only from Bohemia, Saxony, and possibly from Spain. We are enabled to estimate, by the aid of some tables given by Pryce in his "Mineralogia," the production of tin in Cornwall for a few years, and from this fragmentary statement it is estimated that about 450 tons were produced on the average in each year. The same authority informs us that in the seventeenth century the average of the metallic tin produced was 1,500 tons per annum. This was, however, only after Elizabeth had introduced a considerable number of German miners. In the reign of Queen Anne (1700 to 1714) there was an accumulation of tin (five years' consumption is spoken of as being equal to 5,000 tons), and great deadness

* Professor J. Rhys, "Celtic Britain."
† Francisco Balducci Pegolotti, "La Pratica della Mercatura."

of trade continued until 1789. The East India Company then becoming speculators, we find the production of tin considerably improved.

G. R. Porter, Esq., F.R.S.,* gives a table from 1750,—when 2,876 tons of tin were raised,—to 1834, when 4,180 tons were produced. The mean average will be 3,000 tons a year, consequently in eighty-four years there will have been produced 252,000 tons of tin. Until within the last twenty years the fluctuations have been very immaterial.

Mr. Porter divides the periods as follows, the average produce of each five years being—

Years.	Tons.	Years.	Tons.	Years.	Tons.
1750 to 1754	2,585	1780 to 1784	2,667	1810 to 1814	2,339
1755 " 1759	2,728	1785 " 1789	3,249	1815 " 1819	3,444
1760 " 1764	2,610	1790 " 1794	3,405	1820 " 1824	3,578
1765 " 1769	2,845	1795 " 1799	3,084	1825 " 1829	4,595
1770 " 1774	2,853	1800 " 1804	2,676	1830 " 1834	4,047†
1775 " 1779	2,647	1805 " 1809	2,572		

In 1820 one-fifth of the tin was "refined tin," but from that date the quantity has been gradually increasing. This is used for preparing *Dyer's liquor* (chloride of tin), and for tinning iron (making *tin-plates*). These were formerly tinned with "grain tin" (tin smelted from the ore found in the tin streams), but the quality of refined metal is so much improved, that by most manufacturers no other tin is now employed. Some few, however, still use common tin for the outer coat of the plate. The annual production of tin for thirteen years from 1848 was as follows:—

Year.		Ore. Tons.	Metallic Tin. Tons.	Year.		Ore. Tons.	Metallic Tin. Tons.
1848	Produce of Tin Ore	10,176	6,784	1855	Produce of Tin Ore	8,947	6,000
1849	"	10,719	7,148	1856	"	9,350	6,177
1850	"	10,383	6,922	1857	"	9,783	6,582
1851	"	9,455	6,304	1858	"	10,618	6,920
1852	"	9,674	6,510	1859	"	10,670	7,100
1853	"	8,866	5,763	1860	"	10,462	6,695
1854	"	8,747	5,947				

In the ten years ending 1849 we imported,—principally from the East Indies,—10,166 tons 15 cwts. During the same period we exported Foreign tin, 7,025 tons; and of British tin 16,078 tons. In the ten years from 1850 to 1859 we produced of—

British Tin		65,098 tons.
Imported Tin, and Regulus		25,324 "
		90,422 "
We exported in the same time—Foreign Tin	4,163 tons	
" " British Tin	16,735	
		20,898 "
Leaving for home consumption—		69,524 "

The consumption of tin in Great Britain in each of the undermentioned ten years shows a rapid increase:—

	Tons.		Tons.
From 1791 to 1800	7,545	or annually	754
" 1801 " 1810	11,179	"	1,118
" 1811 " 1820	16,000	"	1,600
" 1821 " 1830	26,158	"	2,616
" 1831 " 1840	32,542	"	3,365

The cause of this advance in our consumption of tin has been the

* "The Progress of the Nation in its various Social and Economical Relations from the Beginning of the Nineteenth Century." By G. R. Porter. London: 1847.

† Eight hundred tons a year of tin were sent to China for many years.

extension of our tin-plate export. This will be shown by the following statement:—

	Tin Plates. Boxes.	Canada Plates. Boxes.
From Liverpool in 1850 we exported	460,184	11,420
" 1855 "	591,276	11,431
" 1859 "	811,051	24,862

In addition to this, the employment of white metals, such as Prince's-metal, Britannia-metal, German-silver, Albata plate, &c., as the basis upon which electro deposits of silver are made, and the greatly increased use of bronzes, have produced a larger consumption of this metal.

The difference between the imports and our exports of tin will be shown by the following statement:—

	Cwts.		Tons.
In 1820 we imported from Banca	1,309	and the exports were	3,047
1825	4,231		4,709
1830	15,539		10,426
1835	19,704		23,795
1840	9,391		6,594
1845	12,085		19,153

As it regards tin ore (black tin), the following table represents the position of our productive tin mines for ten years, as shown by the returns made to the Stannary Court, which have been carefully corrected by those made to the Inspector of Mines, and to the Mining Record Office:—

Year.	Number of Mines.	Quantity of Tin Ore.	Average Price per Ton.
		Tons.	£ s. d.
1864	174	13,985	60 17 6
1865	156	14,122	55 6 0
1866	145	13,785	48 10 9
1867	117	11,066	50 18 0
1868	109	11,584	55 4 0
1869	117	13,883	69 16 0
1870	147	15,234	75 3 0
1871	145	16,898	78 12 6
1872	162	14,266	87 7 0
1873	213	14,884	78 1 0

The prices of Foreign tin, and a statement of the stocks on hand in each of those years, as they materially influence the value of the tin mines of Cornwall and Devonshire, are given in the following table:—

Year.	Prices per Cwt. Banca.	Prices per Cwt. Straits.	Stock of Foreign Tin.
	s. d.	s. d.	Tons cwts.
1864	107 8	106 1	2,970 0
1865	95 10	92 5	3,287 11
1866	85 2	82 6	3,149 8
1867	91 7	88 0	2,565 11
1868	95 2	93 8	1,756 5
1869	128 6	126 3	1,516 8
1870	126 8	124 2	1,137 16
1871	135 2	133 6	992 8
1872	153 0	145 11½	1,759 15
1873	135 3	133 3	1,507 0

The actual production of the Dutch tin mines in each of those years was as follows:

Year.	Banca.	Billiton.	Total.	Year.	Banca.	Billiton.	Total.
	Tons.	Tons.	Tons.		Tons.	Tons.	Tons.
1864 . .	5,343	794	6,137	1869 . .	4,483	2,424	6,907
1865 . .	4,554	1,065	5,619	1870 . .	4,672	2,858	7,530
1866 . .	5,234	1,171	6,405	1871 . .	4,320	3,190	7,510
1867 . .	4,639	2,341	6,980	1872 . .	4,352	3,456	7,808
1868 . .	3,960	2,151	6,111	1873 . .	4,480	3,264	7,744

Our importations of tin, in the form of ore, and as pure tin or regulus, in the last two years, were as follows—the countries named being those from which the largest quantities were received:

	1872.		1873.	
	Tin Ore.	Metal or Regulus.	Tin Ore.	Metal or Regulus.
	Tons.	Tons.	Tons.	Tons.
Straits Settlements . . .	—	6,095	1	4,812
India Dutch possessions . .	—	209	—	—
China	—	280	—	25
Victoria	372	46	207	58
New South Wales . . .	334	4	3,114	331
Queensland	106	—	1,302	103
Tasmania	—	—	13	—
Peru	101	448	671	387
Chili	18	79	157	114

The total imports being in—

1872, 1,024 tons of Ore, and 8,342 tons of Metal and Regulus.
1873, 5,612 ,, ,, 7,791 ,, ,, ,,

This being an increase of 4,578 tons of ore, out of total 18,544 in 1872, and a decrease of 552 tons of tin in the metallic or reguline state.

In 1872 we smelted in this country—

14,266 tons of British Tin Ore, producing	9,560 tons of Tin.
1,024 tons of Foreign and Colonial Tin Ore, producing . . .	642 ,,
And received of Metal and Regulus	8,342 ,,
The total production of British, Foreign, and Colonial Tin being	18,544 tons.

In 1873 we smelted in this country—

14,884 tons of British Ore, producing	9,752 tons of Tin.
5,612 tons of Foreign and Colonial Ore, producing . . .	3,650 ,,
And received of Metal and Regulus	7,791 ,,
The total production of British, Foreign, and Colonial Tin being .	21,193 tons.

The loss in refining the regulus, and some of the Foreign tin, is not of great importance, therefore it is not taken into account in either year.

The exports of tin of British production in 1873, and the two previous years, were, according to Board of Trade returns—

In 1871, 114,201 cwts.
,, 1872, 113,871 ,,
,, 1873, 115,946 ,,

The exports of tin of Foreign and Colonial production were—

In 1871, 41,196 cwts.
,, 1872, 48,634 ,,
,, 1873, 28,869 ,,

That is, of British, and Foreign, and Colonial tin, we exported—

In 1871, 7,769 tons.
,, 1872, 8,124 tons, an increase of 355 tons.
,, 1873, 7,250 tons, a decrease of 874 tons.

This statement, which is as nearly correct as it is at present possible to make it, will place before the reader the position of our tin trade in 1873, and enable the tin miner to calculate his prospects in future years.

It must be remembered that, in addition to the tin which we have for a long period been steadily receiving from Banca and Billiton, a new tin-producing district of great value is being opened out in the Malacca Peninsula, and that an English company are commencing operations in a large and promising district of Siam, said to be rich in stream tin.

It will be seen by the table given below that the Banca and Billiton sales have remained tolerably uniform for the five years ending 1881, but that the Straits shipments have shown a rapidly increasing rate. During the past three years large quantities of tin ore have been raised in Siam and the Malayan peninsula, the principal portion of which has been sent to China:—

	1877. Tons.	1878. Tons.	1879. Tons.	1880. Tons.	1881. Tons.
Banca Sales	4,324	4,064	4,253	3,038	4,339
Billiton Sales *	3,000	3,970	4,513	4,735	4,735
Straits Shipments	3,014	7,900	10,985	11,660	11,475*

The Australian production has been so large, and the cost of production so small, that the importation of the tin from our colonies has tended to reduce the prices of tin ore in this country very materially. The discovery of stanniferous deposits in New Zealand and Queensland, which promise to produce stream tin of high quality at a low cost, will certainly have the effect of preventing any increase in the price of British tin. The returns from the Australian ports, Sydney, Melbourne, and others, have been as follows for the last ten years:—

Year.	Tons.	Year.	Tons.
1872	150	1877	9,093
1873	2,990	1878	8,650
1874	5,800	1879	7,426
1875	7,210	1880	7,800
1876	8,392	1881	9,000 †

SALES OF TIN IN BILLITON.

	1877.		1878.		1879.		1880.		1881.	
	Piculs.	Average price per Picul.	Piculs.	Average price per Picul.	Piculs.	Average price per Picul.	Piculs.	Average price per Picul.	Piculs.	Average price per Picul.
		Florins.		Florins.		Florins.		Florins.		Florins.
February	10,000	46·87	10,000	$41\frac{5}{8}$	12,000	38^{42}	13,000	63^{13}	13,000	60^{22}
April	10,000	46·42	10,000	$41\frac{1}{4}$	12,000	45^{88}	13,000	56^{23}	13,000	59^{82}
June	10,000	$45\frac{1}{2}$	10,000	41·22	13,000	43^{76}	13,000	47^{20}	13,000	61^{84}
August	10,000	$42\frac{32}{100}$	10,000	$40\frac{3}{4}$	13,000	42^{26}	13,000	58^{62}	13,000	61^{82}
October	10,000	42·37	10,000	36·96	13,000	$56\frac{1}{4}$	13,000	58^{25}	13,000	$66\frac{1}{2}$
December	10,000	43·47	12,000	41·63	13,000	$62\frac{1}{4}$	13,000	61^{60}	13,000	75^{13}

The sales of tin in Holland, and of Billiton tin in Batavia, for the five years ending 1881, will give a correct impression of the manner under which the Banca tin reaches our manufactories.

* Those readers who desire any more detailed description and commercial account of the tin trade should consult "A History of the Trade in Tin." By Phillip William Flower. 1880. (George Bell and Sons.)

† "Banca tin is produced by convict labour in the island of Banca, from whence it is sent across to the port of Batavia, in Java, for shipment to Rotterdam, where it is warehoused, and sold periodically by the Trading Company. Billiton tin is raised by a private company in the Dutch island of Billiton. Sometimes sold on the spot and sometimes sent to Holland for sale."—*Flower's "History of the Trade in Tin."*

—	1877.		1878.		1879.		1880.		1881.	
	Slabs.*	Average price.	Slabs.	Average price.	Slabs.	Average price.	Slabs.	Average price.	Slabs.	Price per 50 kilos.
		Florins.†		Florins.		Florins.		Florins.		Florins.
January	19,800	43⅞	18,300	40¼	19,479		19,937	59	18,297	53¼
March	23,518	42⅓	20,900	40½	23,346		14,988	51¼	23,419	56⅛
May	22,400	42½	20,110	39⅝	23,426		20,162	43⅜	23,489	52⅝
July	23,584	41·05	19,613	39¼	23,300		20,214	57½	23,653	54¼
September	21,635	$40\frac{30}{100}$	24,200	35·8	23,059		20,608	49½	23,414	58⅛
November	24,717	40·95	23,817	39·6	23,500		20,403	56½	23,322	64

The only course open to the British miner for checking the importation of Foreign and Colonial tin, appears to be the exercise of the strictest economy in every branch of production. Into the mines labour-saving machinery must be introduced, and on the dressing-floors every advantage must be taken of such scientific knowledge as is directly applicable to the separation of bodies of different specific gravity, one from the other.

The following general statement will be found useful in studying the progress of tin-mining.

According to the charter of Edmund, Earl of Cornwall, the tin at this time paid a duty of a halfpenny for every pound weight when coined. In the reign of Edward I. the duty was fixed at 4s. for every hundredweight of coined tin. The dues upon tin in Devonshire paid to the Duke of Cornwall have been only at the rate of 1s. 6⅓d. per cwt.

In 1213 the duty payable to the Earl of Cornwall was farmed for 200 marks (of 13s. 4d. each) for Cornwall, about £175, and £200 for Devonshire.‡

In 1337, Edward the Black Prince being then Duke of Cornwall, the profit on the coinage was at first 3,000 marks, and the price increasing it became 4,000 marks, about £3,500, which will represent a produce of 3,698 tons of 20 cwts.

In 1524 the profits of both counties were £2,771 3s. 9½d.

In 1602 (the forty-fourth year of Queen Elizabeth) the coinage amounted to £2,623 9s. 8d. in Cornwall, and £102 17s. 9¾d. in Devon.

In the reigns of James I. (1610) and Charles I. (1630) the produce, according to Lysons, quoting "The Records of the Duchy of Cornwall," varied from 1,400 to 1,600 tons.

In 1742 the Mines Royal Company reported the average produce to have been about 2,100 tons for several years.

From 1750 to 1779 the average produce in each year was about 17,000 blocks, the weight of each block being computed at 3·35 cwts. Converting the blocks into tons, the mean average will be 1,763 tons per annum. From a table produced by the late Mr. John Taylor we find that from 1780 to 1838 the mean average annual produce of tin was 21,132 tons.

For the years 1799, 1800, 1801 the Duchy of Cornwall received £9,620, and in 1814 the revenues of the Duchy of Cornwall for tin was about £8,500. In 1820 Cornwall produced 2,775 tons of tin.§

De la Beche gives a table from midsummer, 1837, to midsummer, 1838, which shows the relative quantity and kind of tin produced.

* 1,000 Banca slabs weigh about 32 tons. † Average price per 50 kilos.
‡ Lyson's "Magna Britannia," p. cclxxx. § "Transactions of the Geological Society of Cornwall."

CORNWALL.

Coinage towns.	Grain tin.	Common tin.
Calstock	—	393 blocks.
Truro	1,345	8,952 „
Hayle	118	5,334 „
Penzance		12,423 „

DEVONSHIRE.

Morwelham	32	674 „

Making a total of 29,321 blocks, or 5,130 tons, of which 1,545, or about one-nineteenth, was grain tin, and 27,776 blocks, common tin.

The following table continues the statement of the annual production from our tin mines to the nineteenth century:—

	Tin Ore. Tons.	Metallic Tin. Tons.
In 1874 the production of Tin was	14,039	9,942
1875 „ „	13,995	9,014
1876 „ „	13,688	8,500
1877 „ „	14,142	9,500
1878 „ „	15,045	10,106
1879 „ „	14,665	9,532
1880 „ „	13,737	8,918
1881 „ „	12,900	8,600
1882 { Inspector's Return 12,157 tons; Streams 886 „ }	13,043	8,694

It must appear to many that the attempt to estimate the total quantity of tin produced from the stream works, and from the mines of this country, since the commencement of the primitive process of searching the alluvial deposits, must prove an abortive one. Under all the circumstances of the case the result must at the first appear to every one as unworthy of attention. It is unhesitatingly admitted that the estimated production of tin, previously to the Norman Conquest, can be little other than a probable guess. It should, however, be stated that the researches of antiquarians sufficiently warrant the expression of an opinion that the Phœnician merchants carried, by the maritime and by the overland route across Europe, in those early days only small quantities at a time. Judging from the existing evidences afforded by the "Jews' Houses," and the slabs of tin which have been discovered in various parts of Cornwall, we have evidence that the smelting operations were on a limited scale. The ships which carried the tin from this country were small, and we are informed that the mules on whose backs the slabs of tin were borne across Europe were rarely weighted with more than one hundredweight of tin.

Until the fourteenth century we are unable to do more than guess at production; but since then we arrive at an approximation sufficiently close to enable us to state that upwards of three million tons of metallic tin have been extracted from our stanniferous deposits:—

In the	500 years before Christ		50,000 tons.
„	500 years of Roman occupation		50,000 „
To	1066	The landing of William the Conqueror	100,000 „
„	1300	Edward I.	369,800 „
„	1500	Henry VIII.	42,048 „
„	1600	Elizabeth	680,100 „
„	1636	Charles I.	30,000 „
„	1740	Computation of Mines Royal Company	235,000 „
„	1834	William IV.	202,000 „
„	1860	Victoria	162,000 „
„	1880	Ditto	195,223 „
			3,016,171 „

Tin streams, and detrital deposits in general, are producing at this time a very small quantity of black tin (*tin ore*). Some of that included in the following table is really derived from tin mines, it being carried away with the waste of the dressing-floors.*

PRODUCE OF TIN STREAMS.

—	——	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881
		T. c.	T. c.	T. c.	T. c.	T. c.	T. c.	T. c.	T. c.	T. c.	T. c.
1	Bushorne's Stream .	..	..	6 8	2 1	..	..	..	..	..	..
2	Carbis Beach . .	..	..	..	..	..	..	..	..	1 1	1 11
3	Chapel Porth . .	0 8		..	..	..	..	..	..	..	..
4	Cleggar Porth . .	0 4	0 13	0 2	..	1 11	1 4	9 0	0 11	0 17	0 7
5	Coombe . . .	..	..	..	1 16	..	..	..	..	..	..
6	Darley Leat . .	4 7	1 9	6 9	3 1	1 14	5 7	..	..	..	..
7	Excelsior Stream .	..	..	..	..	..	4 8	..	..	..	..
8	Goonlaze ,, .	..	..	0 5	0 9	..	..	..	0 4	3 2	..
9	Gwythian ,, .	21 12	..	..	0 9	12 1	..	..	..	..	0 5
10	Helston ,, .	14 19	6 5	5 4	4 14	5 11	4 3	4 0	1 12	1 3	2 18
11	Lelant ,, .	..	..	..	..	..	5 0	3 0	5 10	6 0	6 19
12	Letcha Foreshore .	..	..	9 13	..	..	..	..	..	..	0 13
13	Looe Pool . . .	2 19	3 18	4 14	8 0	..	24 10	12 11	10 1	22 16	..†
14	Menardarva Stream .	..	..	9 13	..	..	..	..	..	..	..
15	Mill Tin ,, .	..	..	4 12	..	..	..	..	..	..	..
16	Nancemellin ,, .	..	..	3 15	..	..	..	..	..	..	..
17	Nanjulian ,, .	..	0 3	..	..	..	..	..	..	..	..
18	Perran Beach . .	..	2 17	..	2 9	..	..	0 5	..	..	..
19	Perran Porth . .	..	2 10	0 12	..	..	..	..	..	..	..
20	Perran River . .	..	0 12	0 9	1 1	..	..	..	..	..	..
21	Porthledden Sands .	..	.	..	0 9	4 8	0 2	0 1	.	1 2	..
22	Polberro Cove . .	16 1	..	..	1 8	..	1 6	..	..	0 7	..
23	Porth Towan . .	..	..	..	..	0 9	0 6	0 6	..	9 1	..
24	Restronguet Stream .	..	..	16 11	..	..	..	..	..	..	..
25	Roseroggan ,, .	..	..	18 13	..	..	..	..	..	..	..
26	Rosewarne ,, .	..	..	..	..	.	..	..	0 15	..	..
27	Short Horn Beach .	..	.	..	..	..	..	..	..	5 13	6 1
28	Trevellas ,, .	..	..	9 2	..	0 16	..	0 12	7 0	0 11	..
29	Trevaunance ,, .	4 11	7 13	14 12	3 13	4 4	4 18	4 2	6 0	2 18	..†
30	Tolbesco ,, .	..	..	..	..	..	..	..	..	0 15	..

COPPER.—It has been shown in the historical sketch that copper was not unknown to the early inhabitants of these islands; but there are many reasons for supposing that all, or nearly all, that was used by the Britons was imported from the Continent, and this was continued until the early part of the sixteenth century. We have evidence that the Romans smelted some

* The produce of the "Red River" and other rivers collecting the waste from the dressing-floors of the tin mines between Redruth and Camborne is not included in the above table. In the five years ending 1881 the following quantities were obtained from this source:—

Year.	Quantities. Tons	cwts.	qrs.	lbs.	Value. £	s.	d.
1877 . . .	689	11	2	0	20,858	0	6
1878 . . .	736	11	2	0	19,433	15	4
1879 . . .	762	14	2	15	21,876	1	1
1880 . . .	818	7	3	7	36,810	10	6
1881 . . .	909	1	1	0	35,283	0	0

It has been frequently argued that this large quantity of tin ore should not—if the dressing arrangements were perfect—be allowed to flow away from the dressing-floors as waste. On the banks of the Red River there are seventeen separate establishments fitted with a good description of machinery, and on the river flowing from Carn Brea and Tincroft, joining the above at Tehidy Mill, there are eight other sets of dressing machinery at the present time. There may be a few small streams occasionally worked. Some tin is still obtained from the China Clay Works, and at intervals, discoveries are made of detrital tin in places where there was no suspicion of the existence of such a deposit. During the year 1882 a small quantity was discovered in some land in the parish of St. Paul, on the western side of the Mount Bay.

† The later returns from Looe Pool include the streams in Wendron, Sythney, Breage, &c.

copper from British ores during their occupation. Dr. Percy, in his "Metallurgy," says *: "I am informed by Mr. Albert Way and Mr. Franks, the eminent archæologist, that lumps of metallic copper, more or less rounded, have been discovered in different parts of the country, but always in association with articles of bronze. Mr. Franks showed me one of these lumps, which evidently had been melted, and which, on examination in the Metallurgical Laboratory, proved to be practically pure copper."

It will be remembered that Professor Phillips† says: "There is, I believe, no instance of a single bit of pure tin or pure copper being found with the numerous 'celts' which occur in so many parts of England." Cæsar informs us that the brass—meaning brass or bronze indifferently—used by the natives of Britain, was imported. It is tolerably certain that bronze vessels, and tools, and weapons, were made in this country; but the probability is that the copper used by the Britons in their manufacture was imported.

In Anglesea—where the copper ore came up to the surface—and in some other parts of North Wales, there is evidence that copper was smelted at an early period by the Romans, or by the Celtic slaves under their direction. The cake of copper found at Caerhem or Caer-Hen, near Conway, described by Pennant,‡ proves that copper was procured in these islands, but the quantity must have been quite insignificant. We really have no evidence, before the time of Elizabeth (1558), on which any dependence can be placed. Then, in all probability, the German miners introduced by that queen first worked our copper mines. These mines have really only risen into importance since the commencement of the eighteenth century. From that period until about 1852, there was a steadily increasing annual rise, the quantity produced in that year being nearly 209,305 tons. The produce of the Cornish copper mines regularly declined from that year, until in 1881 we find the quantity sold at the Ticketings is reduced to 40,584. It will be seen, from TABLES printed in the Appendix, that commencing in 1726, with a produce in the mines of Cornwall of 5,000 tons, the quantity increased steadily to the year above named. The total production of copper ore in the United Kingdom, and of metallic copper obtained from native ores, shows that in 1856 our copper mines produced 218,659 tons, yielding 14,775 tons of copper, whereas in 1880 all our mines gave us only 52,118 tons of ore, yielding 3,662 tons of metal.

The following table, showing the variations in the average prices of Cornish copper ore, will be found to be of importance to our argument.

Year.	£ s. d.	Year.	£ s. d.
1700	2 10 0§	1805	10 1 10
1730	7 15 10	1814	8 15 4
1750	7 6 6‖	1822	6 7 0
1779	5 16 0	1832	6 1 6
1797	7 13 8	1842	6 4 4

* "Metallurgy: the Art of extracting Metals from their Ores, and adapting them to various Purposes of Manufacture." By John Percy, M.D., F.R.S.

† "Thoughts on the Ancient Metallurgy and Mining in Brigantia and other Parts of Britain." By John Phillips, F.R.S.A.

‡ See p. 41. § "Borlase's "Natural History of Cornwall."

‖ In 1758, Borlase says: "Yellow ore now sells for a price between ten and twenty pounds per ton." This would have been ore of highpercentage produce.

The low price of copper ore in 1779 arose from the large quantities of copper thrown into the market from the mines in Anglesea, which up to 1784 were said to be producing 3,000 tons of copper annually.* About the same period the copper mine at Ecton Hill, in Staffordshire, was discovered: its most productive period being about 1780.

It is not necessary that the evidence already given should be re-stated. Pryce tells us that, in 1737, 9,000 tons of ore were raised. The approximate value of the copper obtained in 1760 was £66,825. By comparing this with the value of the ores raised in 1837 we find an increase in the same of four times and two-fifths nearly (*De la Beche*). We have seen that in 1877 the quantity of copper raised in Cornwall reached its maximum, 14,091 tons.

The copper mines of Devonshire produced in 1801 1,078 tons of ore. This quantity steadily increased until, in 1837, 6,328 tons of ore were raised.

A little copper has been raised from the neighbourhood of Doddington, on the north-east of the Quantock Hills. Twenty-eight tons of copper were obtained in Somersetshire in 1821; and Mr. Leonard Horner† drew attention to green and blue carbonates of copper worked in the Red Sandstone Conglomerate down upon the lode in the grauwacke beneath.

Shafts have been sunk near Minehead without any profitable return; and for the last half century no copper ore of any consequence has been produced in Somersetshire.

The fact of there being a lawsuit, between Elizabeth and the Earl of Northumberland, relative to a copper mine at Keswick, proves that it was a mine of some importance; indeed, 4,000 men are said to have been employed there.‡

Camden says much good copper was for a *long time* made at Keswick, where the works were established in 1566, and Newland, where in 1709 the miners found eleven veins, but we know nothing of their value; but in 1671 Webster§ wrote, "Now the Work is quite left and decayed, yet I am informed that some do now melt forth as much very good copper, as serveth them to make half-pennies and farthings."

Edward III., in the fifteenth year of his reign (1341), granted to a company of nine adventurers, who were headed by Richard, Duke of Gloucester, certain copper mines in Alston Moor, and near Richmond, in Yorkshire. That the quantity of copper ore raised at this period was comparatively small appears from the fact, that copper was imported into England from Hungary and Sweden, and that Calamine was exported as ballast.

The valuable work of the late Colonel Grant Francis‖ gives several curious letters, the substance of which has been already quoted, which show that very small quantities of copper ore were raised in Perranzabula, and from two or three other mines in Cornwall, and smelted there in 1583. The following quotations appear to prove this:—

* Plot's "History of Staffordshire."

† "Transactions of the Geological Society of London," vol. iii.

‡ "Some Account of Mines, and the Advantage of them to the Kingdom." By Thomas Heton, M.A. London: 1707.

§ "Metallographiæ," &c. By John Webster. London: 1671.

‖ "The Smelting of Copper in the Swansea District from the Time of Elizabeth." By Grant Francis.

1. "Y't you have not above 50 tons gotten in all."

2. "I measured and received this last week at Logan 10 tons of good and clean sorted copper ore." (1584.)

3. "We have in readiness as much copper roste, and blake copper, as will make 20 tonne of good fine copper." (1586.)

4. "The 14th October, 1585, came John Bwaple, one of Wales, w'h his bark for a frayght of copper owre, and did deliver him, the 21st October, 15 tonn. and 8 Hundred of copper owre for Wales. * * I received his fraight at St. Ives, and for my lyffe I could not get any owre from St. Yeust." (St. Just.)

These statements sufficiently show that, at the period named, the production of copper in Cornwall was small. We learn from Pryce,* that the rich black oxide of copper was, in the beginning of the eighteenth century, thrown away by the tinners, under the name of *poder*, and that several thousand pounds' worth were formerly washed down into the sea from Old Poole mine. Mr. J. Carne, writing in 1824,† says that for fifty years the miners of Wheal Jewell threw away these rich ores (oxide of copper) in ignorance of their value. The author was informed that the family of the Williams's, who were then working Tresavean mine most profitably for tin, caused all the workings to be given up "because they had come to the yellows" (copper pyrites, yellow copper ore).

Dr. Borlase says that the *copper pyrites* was always known to the tinminers as *poder*, but De la Beche ‡ with much reason says: "As *poder* means *dust*, which would agree with the appearance of this friable ore (the black oxide of copper), it may be questionable how far Borlase may have been correct in stating that yellow copper ore was thus named. As *poder* has this meaning, may not the name be a provincial manner of pronouncing the English word *powder*?"

The same authority, in his "Natural History of Cornwall," states that Mr. Beauchamp of Gwennap, "at this time covenanted to sell all the copper which he should rise out of a well-stocked mine for twenty years at £5 per ton, and the ore at Relistian, in Gwinnear, was covenanted for at £2 10s. per ton."

There is not much doubt but that copper ore was found in Cornwall associated with the tin from a very early period. Native copper was sometimes found at shallow depths, and we are told that a small parcel was sold to the Cornish Copper Company, from a *deep situation* in Cook's Kitchen.

About 1690, some speculators came into Cornwall from Bristol, and purchased copper ores at the rate of £2 10s. to £4 per ton. Mr. Thomas Coster§ of Bristol, with other persons, are said to have become adventurers in the Cornish copper mines. This Thomas Coster was lessee in 1746, with Partners, of the copper works built on lands leased by the last Lord Mansell, known as the "White Rock" Copper Works.

This Mr. T. Coster appears to have introduced into Cornwall a better system of draining the mines, of dressing the copper ores, and assaying them.

* "Mineralogia Cornubiensis."
† "Transactions of the Geological Society of Cornwall," vol. iii.
‡ "Report on the Geology of Cornwall and Devon."
§ De la Beche calls him *John Costar;* Colonel Francis, always *Thomas Coster*.

He bought, it is said, 2,100 tons of copper from North Roskear mine, 1,400 of which had been lying unsold on the mine for years. He is said by Pryce to have made a profit of not less than £60,000 in a few years by his speculations in copper.

From this time we obtain a tolerably correct return of the copper ore raised from the Cornish mines.

The average produce of the copper ores smelted from all the mines of Cornwall for about sixty years,* appears to have been as follows:—

Years.	Tons of Ore.	Tons of Copper.	Produce per Cent.
1771	27,896	3,347	12
1781	28,749	3,459	12
1791	Records lost		—
1800	53,981	5,187	$9\frac{6}{10}$
1801 to 1810	67,532	6,059	9
1811 „ 1820	78,569	6,602	$8\frac{1}{2}$
1821 „ 1830	114 040	9,143	8
1831 „ 1837	142,785	11,637	$8\frac{1}{2}$

Sir Charles Lemon—who was ever anxious to place the mines and the miners of Cornwall in a more satisfactory position than that which had prevailed for so long a time, communicated his paper to the Statistical Society, in the hope of being enabled to show the necessity of keeping records of progress—writes thus, with especial reference to the contemplated "Mining Record Office": "The sketch I here offer is slight, and some of the tables are avowedly imperfect, but they will shortly be replaced by the results of an inquiry taken up at the suggestion of the British Association, and now in the hands of a person having far better opportunities than I possess of obtaining information."

About 1768 the great mines in Anglesea were discovered and actively at work. In 1784, 64,800 tons of copper ore, about 3,000 tons of fine copper, are stated to have been produced annually from Mona and Parys Mountain mines. To 1798 the profit is given as £2,257,291 sterling.

For more than fifty years the Ecton and the neighbouring mines in Staffordshire are said to have yielded a profit exceeding £70,000 per annum; and Mr. Walter Eddy states that "coming back to recent times (1777), I find, from documents left in the Mine Office, that in twenty years, between that date and 1797, 44,769 tons of copper ore were raised, giving on the average 15 per cent. of copper, and realising £12 a ton." This copper mine was known to Dr. Plat, who wrote in 1686. Farey tells us that "most immense quantities of copper were extracted before 1770." In 1781, he says, "the copper ore seems nearly or quite exhausted."

The copper mines near Keswick and other places in the northern counties were worked for several years, as, in 1684, "Letters" were published asking "What quantity of copper is left upon the place?" that is, in the mines around Keswick.

Copper ore was obtained from the mines in Wales and from those in Scotland, but there was never any large production recorded.

The Mucross mine in Ireland produced for some time 200 tons of copper ore a month. The total value of that which was raised in four years was £80,000.

* "Statistics of Copper Mines of Cornwall." By Sir Charles Lemon, Bart., M.P. ("Journal of the Statistical Society of London," vol. i. p. 65.)

Tables, compiled by the author, were published in the "Memoirs of the Geological Survey," giving the production of copper from all the mines in Cornwall for the years 1845–47, with the average price per ton—the "standard" and produce. The following is an abstract of these tables:—

1845.			1846.			1847.		
Copper Ore. Tons.	Copper. Tons.	Produce.	Copper Ore. Tons.	Copper. Tons.	Produce.	Copper Ore. Tons.	Copper. Tons.	Produce.
162,557	12,883	7½	150,431	11,850	7⅞	155,985	12,754	8¼

From the commencement of the public sales of copper ore at Swansea from 1804 to 1847, the total production was:—

Copper Ore.	Tons.
From the Welsh Mines	53,701
The Sale from the Irish Mines	363,339
Ticketings from English Mines, from 1815 to 1847, being only	22,521

Accompanying these tables there was a diagrammatic chart showing the produce of copper ore in Cornwall for a century, and the fine copper produced during sixty-five years:—

In 1744 the copper ore was about	7,000 tons.
„ 1747 it fell to	4,700 „
„ 1757 it rose to	16,000 „

And, with very few undulations, the production steadily increased until in 1840 it rose to 155,000 tons, falling back in 1843 to 135,000 tons. The fine copper, in 1771—the earliest reliable record—was 3,500 tons, which in 1830 rose to 12,000 tons, and for several years oscillated between that quantity and 9,500 tons. Between 1771 and 1844 we have records of the copper raised in Cornwall, which amounts to about 146,000 tons.

Mr. G. R. Porter* gives the copper raised in the United Kingdom from 1820 to 1834 as follows:—

Year.	Tons.	Year.	Tons.	Year.	Tons.
1820 . .	8,127	1825 . .	10,358	1830	13,232
1821 . .	10,288	1826 . .	11,093	1831	14,685
1822 . .	11,018	1827 . .	12,326	1832	14,450
1823 . .	9,679	1828 . .	12,186	1833	13,260
1824 . .	9,705	1829 . .	12,057	1834	14,024

Since 1834, says Mr. Porter, the produce of copper smelted from English ore cannot be accurately distinguished from that of Foreign origin.

The general state of the copper mines of Cornwall for seven years, ending 1798,† appears to have been as follows:—

The Adventurers' ore in that time amounted to a value of	£2,237,291
The total cost of working	2,195,123
The net profit for 7 years	42,168

Appended will be found several tables showing the actual production of copper ore from the United Kingdom and the metallic copper obtained from it since 1856. These tables convey to those who are interested in the subject all the available information. An attempt has been made to estimate, as in the case of tin, the total quantity of copper ore which has been obtained by mining in these Islands. From the circumstances that copper ore has been obtained from mines in every part of the country, and that some of the ore has been smelted at local works—sometimes on the mine—that portions have been sold at the public sales (*Ticketings*) in Cornwall

* "The Progress of the Nation in its various Social and Economical Relations from the Beginning of the Nineteenth Century." London: 1847.

† "Copper Mines and Copper Trade Report, 1799."

and at Swansea, and other portions purchased by private contract, it has been found almost impossible to arrive at any final result which would not be more or less delusive.

An attentive examination of all available authorities and of such collateral evidence as can be obtained, leads to the belief that the following may be accepted as a fairly correct approximation to the extent of exhaustion which has been going on in the copper mines of the British Isles :—

	Tons of Copper.
a During the Roman Occupation ore was probably raised, which produced	5,000
b To the time of Edward III. (1341)	15,000
c To the reign of Elizabeth, and after the introduction of German miners (say 1600)	47,000
d To the beginning of the Eighteenth Century	100,000
e To 1775—*Copper ore raised* 693,500 tons	37,500
f To 1800 „ „ 1,450,000 „	78,500
g To 1835 „ „ * 3,150,000 „	167,000
h In 1855 „ „ † 4,370,000 „	218,000

From this period to the present time the annual returns have been as follows :—

COPPER ORE AND COPPER FROM THE MINES OF THE UNITED KINGDOM.

Year.	Copper Ore Tons.	Copper. Tons.	Year.	Copper Ore. Tons.	Copper. Tons.
1856	218,659	14,775	1869	129,953	8,291
1857	215,689	14,375	1870	106,698	7,175
1858	218,698	14,456	1871	97,129	6,280
1859	236,789	13,594	1872	91,893	5,703
1860	362,696	15,968	1873	80,188	5,240
1861	312,487	15,331	1874	78,521	4,981
1862	224,417	14,843	1875	71,528	4,323
1863	200,947	14,247	1876	79,252	4,694
1864	214,604	13,302	1877	73,143	4,486
1865	198,298	11,888	1878	56,094	3,952
1866	180,378	11,153	1879	51,035	3,462
1867	158,544	10,233	1880	52,118	3,662
1868	157,335	9,817	1881	52,556	3,875

It will be interesting and instructive to give a statement, here compiled from actual returns furnished to the Mining Record Office, which will show the duration of our copper mines. During thirty years the number of Cornish copper mines selling upward of 5 tons of copper ore annually appear to have existed—

35 mines lasting 20 years and upwards.
40 „ „ 10 years, but under 20 years.
31 „ „ 5 years, but under 10 years.
114 „ „ less than 5 years.

The highest average percentage produce of the 220 mines for the entire period above named was 7⅛.
The lowest produce of one mine was 2⅞.
The highest produce from one mine was 20⅜.

* Mr. Porter ("Progress of the Nation, 1847") gives the value of tin and copper raised in Cornwall at different periods during the present century :—

1801.	Tin and Copper	£731,035	1821.	Tin and Copper	£871,562
1806.	„	1,074,872	1826.	„	1,137,045
1811.	„	901,978	1831.	„	1,106,935
1816.	„	925,083	1834.	„	1,209,762

† "The total quantity of copper ore raised in Ireland I believe to approximate at present (1845) closely to 25,000 tons per annum." ("The Industrial Resources of Ireland." By Dr. Robert Kane, M.D.)

The production of copper in all parts of the United Kingdom was carefully obtained for the three years 1859, 1860, and 1861. The table given below shows the quantities produced at a period when copper mining was fairly successful.

COUNTIES, &c.	Number of Mines. 1859.	1860.	1861.	Copper Ore. 1859.	1860.	1861.	Fine Copper. 1859.	1860.	1861.
ENGLAND AND WALES.				Tons.	Tons.	Tons.	Tons.	Tons.*	Tons.
Cornwall	121	96							
Devon				183,498	182,534	181,594	12,202	12,210	11,663
Cumberland and Lancashire				3,225	2,628	2,331	624	184	168
Anglesey				8,386	7,713	8,792	448	416	486
Carnarvon				2,252	2,623	2,079	99	114	109
Cardigan				35	75	67	3	5	5
Montgomery				..	..	115	..	..	8
Isle of Man				35	753	1,485	26	53	93
Cheshire				10,27	227	335	427	155	215
Total for England & Wales	47	137	139	208,021	196,553	196,798	12,829	13,137	12,747
				Estimated Value.					
				£ 1,379,801	£ 1,259,660	£ 1,118,810	1,532,996	1,414,745	1,307,842
IRELAND.				Quantities.					
				Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Cork	2	3	4	4,536	6,466	7,350	474	651	780
Tipperary	3	..	..	298	..	..	29	..	..
Waterford	1	1	1	6,090	7,765	6,670	635	756	667
Wicklow*	3	6	3	3,238	4,180	1,641	106	586	27
Clare	1	..	..	96	..	..	4	..	..
Total for Ireland	10	10	8	14,258	18,411	15,661	1,248	1,993	1,474
				Estimated Value.					
				£ 108,171	£ 167,540	£ 141,263	£ 125,215	£ 206,564	£ 151,232
Copper ore purchased by private contract from sundry districts not included above				Quantities.					
	14	23	20	Tons. 14,510†	Tons. 21,732	Tons. 19,028†	Tons. 693	Tons. 838	Tons. 1,110
				Estimated Value.					
	..	..	..	£ 18,863	£ 79,983	£ 104,654	£ 76,489	£ 84,952	£ 113,406
Total for England, Wales, and Ireland				Total Quantities.					
	171	170	167	Tons. 236,789	Tons. 236,696	Tons. 231,487	Tons. 15,770	Tons. 15,968	Tons. 15,331
				Total Estimated Value.					
	..	..	..	£ 1,506,835	£ 1,507,183	£ 1,364,727	£ 1,734,700	£ 1,706,261	£ 1,572,480

The following table will show the average percentage produce of the mines with reference to the length of time during which they continued at work:—

* In addition to these copper ores, some copper is separated from the iron pyrites of Wicklow.
† Including some iron pyrites from which copper is separated.

PRODUCE OF FINE COPPER.	35 Mines at work upwards of 20 Years.	40 Mines at work upwards of 10 Years but under 20.	31 Mines at work upwards of 5 Years but under 10.	114 Mines at work less than 5 Years.
Average percentage produce of fine copper	7 3/8	7 5/8	7 7/8	8 1/8
Highest average percentage produce of a single mine	13 5/8	14	14 1/8	26 1/8
Lowest average percentage produce of a single mine	4 3/8	4 7/8	5 1/8	2 7/8
Number of mines producing above 25 per cent. of copper	—	—	—	2
,, ,, ,, 15 per cent. of copper	—	—	—	4
,, ,, ,, 10 per cent. of copper	2	4	2	13
,, ,, ,, 5 per cent. of copper	32	34	29	70
,, ,, ,, less than 5 per cent. of copper	1	2	—	8

AVERAGE PRICES, PRODUCE, AND STANDARD OF CORNISH COPPER ORE, from 1872 to 1881 inclusive:—

Year.	Average Price. £ s. d.	Average Produce.	Average Standard. £ s. d.	Year.	Average Price. £ s. d.	Average Produce.	Average Standard. £ s. d.
1872	4 13 6	6 1/2	114 17 0	1877	4 4 6	6 3/4	103 3 0
1873	4 8 0	6 1/2	110 5 0	1878	3 6 0	7	90 15 6
1874	4 5 0	7 1/8	97 16 0	1879	3 8 6	6 7/8	86 14 0
1875	5 0 0	7	110 0 0	1880	4 4 6	6 7/8	95 0 0
1876	4 17 0	6 3/4	113 8 0	1881	4 5 6	6 5/8	94 8 0

The annual returns from the copper mines of Cornwall and Devonshire are given in the Appendix. The copper ore obtained in other parts of the United Kingdom is shown in the following table, which gives the produce, in alternate years, of the copper mines beyond those of the West of England:—

		1871	1873	1875	1877	1879	1881
ENGLAND.		Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
CHESHIRE	Alderley Edge	8,608	8,122	8,236	6,288	—	—
LANCASHIRE	Coniston	1,423	1,392	1,873	646	108	514
YORKSHIRE	Merrybent	10	72	—	—	—	—
CUMBERLAND	Caldbeck Fells	300	} 86	146	6	—	—
	Rough Tengill	271		—	—	—	—
	Stow Crag	11	—	—	—	—	—
STAFFORDSHIRE	Ecton	1	—	—	—	—	—
WALES.							
MONTGOMERYSHIRE.	Nant-y-Ricket	—	—	—	—	6	—
	Great Gias	—	—	55	18	—	—
	Great Dyliffe	—	—	—	26	—	—
	Moel-fadian	—	5	—	—	—	—
	Severn	—	—	—	—	2	—
CARNARVONSHIRE	Drws-y-Coed	—	100	60	150	200	140
	Symdde Dylluan	30	199	38	—	—	—
	Tan-y-Bwlch	—	—	29	244	333	587
	Derwen-Deg	—	—	—	—	25	20
	Carnarvon Consols	—	—	—	—	—	52
DENBIGHSHIRE	Dyffryn, Mid and South	—	—	—	10	156	—
MERIONETHSHIRE	Glasdir	—	—	16	—	—	78
	Blaen Calan	—	—	—	—	—	7
CARDIGANSHIRE	Darren, South	101	71	79	—	—	192
	Glog-fawr	—	—	—	—	156	—
	Cambrian	—	—	—	100	300	67
	Cwm Erfin	13	—	—	—	—	—
ANGLESEA	Parys Mountain	2,507	1,938	2,704	2,153	180	863
	Do., *Precipitate*	168	120	205	150	100	—
	Mona	3,000	1,628	600	1,040	766	3,804
	Do., *Precipitate*	—	297	400	270	202	—
	Parys, East	—	—	22	—	—	—
ISLE OF MAN.	Bell Abbey, &c.	—	—	—	—	—	—
	Brada Head	—	—	—	—	—	60
	Gt. Laxey	100	—	—	—	—	—
	Rushen	80	—	—	—	—	—

		1871	1873	1875	1877	1879	1881
		Tons.	Tons.	Tons.	Tons.		Tons.
IRELAND.	Berehaven . .				2,188	1,974	2,529
	Ballycummisk .				32	—	
	Ballygaham . .	576	301		46	10	
	Do., *Precipitate*		18		10	11	
	Cooshen . .				9	—	
	Cronebane . .			847	1,962	30	29
	Do., *Precipitate.*			—	3	—	—
	Knockmahon .			2,076	1,143	42	76
	Tigrony, *Precipitate*		23	29	70	26	29
	Ballymurtagh .	90		155			
	Do., *Precipitate*	8		17			
	Errisbeg . . .						40
SCOTLAND.	Sandlodge (Shetland) .				314	778	—

Alderley Edge is a deposit of copper in Sandstone, the produce being very low. The mines of Anglesea are remarkable for a curious compound ore known as "*Blue Stone*," and a similar* ore has been found in Wicklow, Ireland. The quantity of this raised being as follows:—

1871 .	Mona Mine . .	200 tons.
1873 .	" " . .	414
1875 .	" " . .	500
	Parys Mountain .	150
1879 .	Mona Mine . .	548
	Morfa Du . .	1,532
	Connoree, Wicklow .	368

The Irish mines returned in 1879 cupreous pyrites as follows:—

Ballygaham, 1,039 tons. | Cronebane, 2,290 tons. | Tigrony, 3,249 tons.

The total value of these ores being £5,139. These ores are chiefly valuable for the sulphur which they contain; they also contain about 2 per cent. of copper, a little silver, and traces of gold.

A satisfactory idea of the real condition of the copper trade of this country will be formed by studying the following table, which gives the quantity of metallic copper obtained from various sources during the past ten years, Colonial and Foreign, in addition to that raised from our own mines:—

—	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880	1881
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Colonial and Foreign ores sold at Swansea	3,650	3,077	3,489	4,847	3,743	5,399	5,832	2,512	2,374	1,949	1,400
Colonial and Foreign ores sold by private contract (estimated).	6,080	5,150	6,746	5,297	6,340	5,850					
Colonial and Foreign regulus and precipitate sold at Swansea	96	431	618	. .	750	832	30,750	27,914	12,898	7,796	7,110
Colonial and Foreign regulus and precipitate sold by private contract (estimated) .	5,924	4,630	3,085	8,750	16,140	15,762					
Pyrites producing Copper (burnt ore) .	7,900	8,500	12,800	9,000	9,600	15,000	17,000	14,443	14,158	15,000	14,000
Precipitated copper obtained from cupreous pyrites . . .	. .	. .	. .	. .	. .	. .	. .	13,173	21,653	20,500	19,973
Totals .	23,650	21,788	26,738	27,894	36,573	42,843	53,582	58,042	51,083	45,245	42,483

* The blue stone occurring in Anglesea contains sulphide of copper, zinc, and silver lead. That which occurs in Ireland is a compound of equal parts of sulphide of lead and zinc containing silver.

When we learn from the table of the production of copper ore from British mines, and see that our industries for the years 1878 to 1881 did not exceed 4,000 tons of metallic copper, it will be evident that the present depression of our copper trade is due to the large importation of copper from our Colonies and from Foreign countries.

In addition to the above, old copper for re-manufacture, unwrought and part wrought, were also imported. The following table gives the particulars of these,—with the amount of copper ore and regulus, according to custom-house returns,—and the value of the imported copper manufacture:—

—	Ore.	Regulus.	Old for re-manufacture.	Unwrought and part Wrought.	Value of Copper Manufactured.
Year.	Tons.	Tons.	Tons.	Tons.	£
1872	43,650	28,779	731	47,669	71,278
1873	50,769	27,908	743	34,535	61,662
1874	47,866	28,424	1,309	37,754	86,211
1875	53,663	32,906	1,497	39,728	72,670
1876	74,966	27,904	—	39,145	—
1877	93,457	33,701	—	39,743	—
1878	103,945	30,410	3,293	39,360	12,631
1879	87,829	45,930	2,866	40,670	45,763
1880	100,420	45,055	3,162	36,509	94,296
1881	102,040	44,216	—	32,170	—

	British Copper Exported. Unwrought, Wrought, and Mixed Metal.		Foreign and Colonial Copper Re-exported. Wrought and part Wrought.	
Year.	Cwts.	Value.	Cwts.	Value.
1875	735,709	£3,237,529	14,689	£1,258,536
1876	709,889	2,934,191	17,234	1,378,383
1877	798,615	3,059,909	14,157	1,036,970
1878	888,842	3,096,836	—	—
1879	970,168	3,071,300	17,837	1,103,595
1880	973,274	3,315,416	14,895	998,880
1881	1,025,272	3,438,555	13,790	876,367

The copper production in the United States of America has shown a steady increase from 1872. This table has been compiled by Mr. James Duncan Smith, one of the directors of the Arizona Copper Company (Limited), published in *Engineering*, June 8th, 1883.

1872	28,000,000 lbs.	1878	43,000,000 lbs.
1873	31,000,000	1879	46,000,000 ,,
1874	34,000,000	1880	57,000,000 ,,
1875	37,000,000	1881	70,000,000 ,,
1876	40,000,000	1882	88,000,000 ,,
1877	42,000,000		

The consumption of copper in the United States is given—

In 1872	34,000,000 lbs.
,, 1882	77,000,000 ,,

This increased consumption has been due to the manufacture of wires for electrical purposes. At first it was necessary to import copper for their own use to the United States, but for some years no importation has taken place.

Price in 1872	35 cents.
In 1882, highest price	20¼ ,,
,, lowest price	17½ ,,

Our principal imports for each of the five years to 1881 have been from the Cape of Good Hope, British North America, Chili, and other countries, as follows :—

Year.	Copper Ore. Tons.	Regulus and Precipitate. Tons.	Unwrought and part Wrought. Tons.
1877	115,466	33,701	40,216
1878	102,945	33,410	39,360
1879	87,829	43,930	46,670
1880	99,849	45,001	36,509
1881	102,640	44,216	32,170

This continued increase in production from the countries named, and from others where recent discoveries of great value have been made, renders it improbable that our native copper mines can be expected to prove profitable for some time to come.

LEAD AND SILVER.—Both these metals were probably known to the Britons before the invasion of Julius Cæsar. The evidences given show that lead was worked by the Romans rather extensively in many parts of Britain. The pigs of lead found in England and Wales, already described, having Latin inscriptions impressed upon them; with often the statement that the silver had been recovered from the poorer metal, show that the Romans were both miners and metallurgists. Roman mines and scoria are found on the Mendip Hills, Somersetshire, in Derbyshire, in Shropshire, in Northumberland and Cumberland, and in the Lake District.

The Romans used lead largely: they made tanks for water of that metal and pipes to distribute that useful fluid. They buried their dead in leaden coffins, and even lined some sepulchres with it. They must therefore during the period of their occupation have used large quantities of lead: it would be a random guess to say what quantity. Cicero writes to Atticus, saying there was not a scruple of silver in the whole island.* Cicero's knowledge must have been very imperfect, since Strabo reckons gold and silver amongst the products of Britain. In the time of Augustus silver was coined in Britain, and this was no doubt obtained from the lead ores of these islands.

Lister states that he proved the existence of silver in the lead of at least thirty mines.† The lead ores of Shropshire and Derbyshire contain less silver than those from any other mining district. Dr. Watson‡ says there were in his time annually smelted in Derbyshire ten thousand tons of lead ore, but he adds in a note, "This estimate I have reason to think too high." He then informs us that a cubic foot of the lightest of the lead ores of Derbyshire weighed 6,565 ounces, and the heaviest 7,636 ounces. The mean weight of six pieces of this ore may be expressed by 7,342 avoirdupois ounces, whereas the Doctor estimated the weight of a cubic foot of lead ore from the Isle of Man as 7,115 ounces. It is a fact worthy of note that the mines of Mid-England, extending up to Shropshire, contain but little silver, but as we advance into Wales we find the quantity considerably increasing. For example, the produce of silver from some of the mines of Cardiganshire has been as follows :—

Cwm-symlog	40	ounces to the ton of lead.
Darren Vawr	35	,, ,,
Llanfair Clydogau	60 to 80	,, ,,

* "Etiam illud jam cognitum est, ne que argenti scrupulum esse ullum in illa insula."—*Epist. ad Atticus*, l. iv. E. xvii.

† "Lister de Fontibus," chap. ii.

‡ "Chemical Essays," vol. iii. Third edition. By R. Watson, D.D., F.R.S.

Several of the lead mines of Cornwall and Devonshire have proved to be very rich in silver; the largest quantities separated from the argentiferous galena being from the following mines:—

CORNWALL.			DEVONSHIRE.		
Garras, near Truro	100	ounces to the ton of lead.	Bear Alston Mines	102 to 120	ounces to the ton of lead.
Wheal Pool, Helston	50	,, ,,	South Hooe .	140	,, ,,
Wheal Rose ,,	60	,, ,,	Wheal Betsy .	130	,, ,,

The last mine, near Tavistock, produced in 1806 large quantities of argentiferous galena, and about 1824 from 4,000 to 5,000 ounces of silver were obtained annually from the lead and silver ores of that mine.

The *Silver ore* raised from Herland mine, in Gwinnear, at the beginning of the present century produced above £8,000 sterling. In 1810 silver ores to the value of £2,000 were raised from Dolcoath mine, near Camborne; and at Wheal Brothers and Wheal Duchy, near Callington, in 1812, the value of the silver obtained from ruby and grey silver ores and the black sulphide was valued at £3,000. In recent years the following returns have been made from the Callington mines:

	Tons	cwts.		£ s. d.
In 1877 . .	142	15	(no value given of silver ore produced in Cornwall)	
1878 . .	94	9	valued at	5,806 13 0
1879 . .	27	19	,,	621 18 11
1880 . .	14	8	,,	2,691 17 1
1881 . .	5	18	,,	358 7 0

The following table shows the quantities of lead ore raised in each year since 1870, and gives the quantities of lead returned by the smelter, and of silver separated, with some other particulars of especial interest, the result of extensive inquiries, and constructed with much care to the end of 1880.

—	Lead Ore.	Lead.	Silve	Ore to make 100 Tons of Lead.	Lead in 100 Tons of Ore.	Silver in a Ton of Lead.
Year.	Tons.	Tons.	Ounces.	Tons.	Tons.	Ounces.
1870	98,176	73,420	784,562	133·718	74·783	10·687
1871	93,965	69,007	761,490	136·108	73·470	11·030
1872	81,564	60,420	628,920	135·001	74·076	10·402
1873	73,500	54,283	531,077	135·521	73·784	9·792
1874	76,801	58,777	509,277	129·610	77·154	8·672
1875	77,746	57,433	487,358	135·363	73·875	8·485
1876	79,096	58,667	483,422	135·058	73·053	8·253
1877	80,850	61,403	497,375	131·885	75·823	8·100
1878	77,350	58,023	397,471	133·316	75·010	6·850
1879	66,878	41,635	333,674	129·519	77·210	6·462
1880	72,245	56,949	295,518	126·876	78·527	5·189
1881	64,702	48,587	308,398		—	—
1882	65,001	59,328	372,446*		—	—

From this it will be seen that the produce of the lead mines has not only regularly decreased, but that the amount of silver found in each ton of lead has become less from 1871, with a steadiness which appears to point to some special cause, which we are not enabled to explain. It may possibly be that the silver has a tendency to decrease with the increasing depth, but this is not by any means certain.

It is interesting to give the produce of lead ore and the yields of silver from the most interesting and important Greenside mine, near Penrith.

1872	1,516 tons, yielding 17,000 ounces of silver.		1877	1,600 tons, yielding 15,726 ounces of silver.		
1873	1,369 ,, ,,	16,000 ,,	1878	1,581 ,, ,,	14,075	
1874	1,276 ,, ,,	13,063 ,,	1879	1,527 ,,	15,515	
1875	1,558 ,, ,,	15,809 ,,	1880	1,527 ,,	13,801	
1876	1,758 ,, ,,	7,914 ,,	1881	1,236 ,,	11,954	

* Return of H.M. Inspectors of Mines.

The ore obtained in this mine during the last ten years has been found between two dead tracts on the north and south, running near a quartz felsite dyke.

In the Appendix will be found reliable tables giving the production for many years of the lead mines of Cornwall, Durham, and Northumberland, of Cardiganshire, the Isle of Man, Scotland and Ireland, and of the lead ore received by the Commissioners of Greenwich Hospital.

In 1851 the author published, in the "Mineral Statistics," the following table, showing the production of silver, in the compiling of which he was assisted by the late Mr. John Taylor:—

District producing Lead Ores.	Average Quantities of Pig Lead in each per Annum.	Ounce of Silver in each Ton of Lead.	Ounces of Silver from each District.	Mean Average Value of Silver.
	Tons.			£
Cornwall	7,304	25	255,640	63,910
Devonshire	1,026	40	41,040	10,260
Cumberland	5,702	9	51,318	12,829
Durham, Northumberland, and Westmoreland	13,233	12	158,796	36,699
Derbyshire	4,250	None	—	—
Shropshire	2,769	"	—	—
Yorkshire	5,223	" *	—	—
Cardiganshire, Carnarvonshire, and Carmarthenshire	3,492	15	52,380	13,095
Flintshire and Denbighshire	8,122	7	56,854	14,213
Montgomeryshire and Merionethshire	679	6	4,074	1,018
Ireland	1,380	10	13,800	3,450
Scotland	822	8	6,576	1,644
Isle of Man	1,699	20	33,980	8,495
Totals	55,701	—	674,458	168,614

The following table exhibits in detail the more important causes which have led to the great depression prevailing for the last few years in the lead trade of this country. It will be seen that in the last five years the lead ore produced from British mines has fallen off to the extent of 15,298 tons, and that the quantity of lead imported has for several years shown a considerable increase:—

TABLE OF LEAD ORES, LEAD AND SILVER PRODUCED FROM THEM IN TEN YEARS TO 1881 IN THE UNITED KINGDOM, THE IMPORTS AND EXPORTS, WITH MEAN PRICES.

—	Lead Ore.	Lead.	Silver.	Imports of Lead.	Exports of Lead.	Prices of Lead Ore.	Mean Prices of English Pig.
Year.	Tons.	Tons.	Ounces.	Tons.	Tons.	£ s. d.	£ s. d.
1872	81,564	60,420	628,920	69,841	44,330	13 13 0	20 0 0
1873	73,500	54,235	531,077	62,563	32,010	15 8 0	23 6 0
1874	76,201	58,777	509,277	61,987	36,353	14 13 6	22 2 0
1875	77,746	57,435	487,358	79,825	35,398	15 9 3	22 9 0
1876	79,096	58,667	483,472	80,649	35,921	15 8 0	21 13 0
1877	80,650	61,403	497,375	94,486	42,467	13 19 0	20 11 0
1878	77,350	58,020	397,471	100,141	34,385	10 11 6	16 14 0
1879	66,878	51,635	333,674	102,089	36,776	10 6 0	14 16 0
1880	72,245	59,949	295,518	95,049	33,551	11 6 0	16 17 0
1881	64,702	48,587	308,398	93,400	43,109	10 3 0	14 19 0

* Those three counties do not receive from the smelters anything for silver contained in the ore. It is not, therefore, returned. As a rule, the Shropshire ores may really be said to be non-argentiferous. Derbyshire lead contains only from 1 oz. to 2½ ozs., and Yorkshire varies considerably from 2½ ozs. to 5 ozs. All the silver is, however, separated in the processes of refining lead for the white-lead manufacturer. The mean average annual production of lead from the mines of the United Kingdom, from the earliest period to the present time, may be estimated at 3,000 tons per annum, which will give 7,149,000 tons as the total quantity raised. The silver may be estimated to average five ounces to the ton of lead, which will give 35,754,000 ounces.

Hoping to convey a more exact impression of the variation in the production of lead ore and lead, several tables are given in the Appendix, from which the following respective facts have been drawn:—

1. *The Production from the Lead Mines of Cornwall*, showing that in 1845 10,110 tons of lead ore and 6,063 tons of lead were produced, which gradually declined, until in 1881 764 tons 17 cwts. of lead ore and 408 tons 8 cwts. of lead only were obtained.

2. *An Account of the Production of the Lead Mines of Durham and Northumberland.*—From this we see that in 1845 17,046 tons of lead ore were raised, that in 1866 22,774 tons were obtained, which fell back to 14,186 tons 10 cwts. in 1879, which rose to 18,254 tons 19 cwts. in 1880, but fell again to 17,467 tons 2 cwts. in 1881.

3. *The Production of the Cardiganshire Lead Mines.*—From these important mines—the working of which dates from the Roman occupation—in 1845 5,726 tons of lead ore, giving 3,716 tons of lead, were produced. These in 1862 gave 8,299 tons 11 cwts. of lead ore, yielding 5,443 tons of lead, from which time the production gradually declined, until in 1881 it had fallen to 4,598 tons of ore, equal to 3,381 tons of lead.

4. *The Production of the Lead Mines of the Isle of Man* was in 1845 2,259 tons of lead ore, which gradually increased to 1871, when these mines produced 4,645 tons, which gave 3,334 tons of metallic lead; then each year—with one exception—the production steadily increased, until in 1881 these mines gave 5,675 tons of lead ore, yielding 4,183 tons 12 cwts. of lead, with 84,865 ounces of silver.

5. *The Production of the Lead Mines of Scotland* was in 1845 1,173 tons of lead ore. This steadily and regularly increased, until in 1881 3,806 tons 17 cwts. were produced.

6. *The Production of the Lead Mines of Ireland* shows that in 1845 1,944 tons of lead ore were obtained, which gave 855 tons of lead. This was increased to 4,493 tons of lead ore and 3,222 tons of metallic lead in 1852, which at once fell back, producing for several years with much regularity rather more than 2,000 tons of lead ore, until in 1865 the quantity declined, and this continued until 1881, when the Irish lead mines produced only 848 tons 16 cwts. of lead ore, giving but 636 tons of lead.

7. *The Production from the East and West Allendale Mines and the Weardale Mines* was in 1845 12,200 tons of lead ore and 8,130 tons of lead. The returns of silver were not obtained until 1853, when 11,916 tons of lead ore, giving 9,904 tons of metallic lead and 50,760 ounces of silver, were returned. From that period until 1868 there was but little variation, the production being then 12,360 tons of lead ore. A steady decline set in, until in 1879 only 1,624 tons of lead ore were produced, which rose in 1880 to 3,910 tons, and in 1881 to 3,273 tons, giving 2,454 tons of lead and 16,968 ounces of silver. At this time these important mines were suspended; but operations have been recently commenced anew.

8. *The Total Production of Lead Ore, Lead, and Silver from 1848 to 1871 inclusive*, shows a constant increase, from 78,944 tons of lead ore in 1848 to 93,965 tons in 1871, giving 69,037 tons of metallic lead and 761,490 ounces of silver. From this period the production gradually declined.

9. The other tables are of considerable interest, the first giving the quantity of lead ore paying duty to the Greenwich Hospital, from 1768 to 1845. The second giving the prices of lead at the Grassington Lead Smelting Works belonging to his Grace the Duke of Devonshire, from 178[illegible] to 1843, which is a curious illustration of the variations in the price of a natural product. The last records the prices of English tin per *fodder* from the year 1783 to 1800.

A table has been given which shows that in 1858 the United Kingdom produced 11,556 tons of zinc ore, and that to 1881 there has been a regular increase in the production, until it reached 35,527 tons, falling back in 1882 to 32,538 tons; the prices varying but little; the lowest price being in 1861 when zinc ore was £2 a ton and metallic zinc £2. In 1872, the price of zinc ore reached £4 8s., and in the next year metallic zinc was £26 15s.—the highest price.

A table is also given showing the imports and exports of zinc, and much valuable information, from 1823 to 1858.

ZINC.—That Zinc was used at a very early period in the metallurgical arts is certain, but the metallic character of its ores was not understood, even so late as 1741. Calamine ore was used, and it was regarded as a *semi-metal.* The oxides and carbonates of zinc were regarded as earths, in the sense in which that term was used by the alchemists. As Calamine Earth it was employed in the production of alloys with copper, by the Tyrians, and probably by the Assyrians.

Dr. Watson * says: "The two principal ores of zinc are *calamine* and *blende.* The Arabic word *climia*, or, as it is pronounced by some, *calimia*, denotes the same substance which we call *Lapis calaminaris*, *calamine* or *calamy*; and hence *Salmasius* † is of opinion that they judge very preposterously who would derive *calamine* from *calaem*, an Indian word.

"The other ore of zinc is called by the Germans *blende*, from its blinding or misleading appearance, it looking like an ore of lead, but yielding (as was formerly thought) no metallic substance of any kind.‡ They have in Staffordshire a sort of iron which they call *blende-metal*, of which they make nails, hammers, &c.§ Calamine is found in Somersetshire, Derbyshire, and Flintshire, and other parts of England. Before the reign of Elizabeth, Sir John Pettus says,‖ this mineral was held in very little estimation in Great Britain, and even at so late a period as towards the end of the last century, it was commonly carried out of the kingdom as ballast by the ships which traded to foreign parts, especially to Holland."

"Great quantities of calamine have of late years," says Dr. Watson, writing in 1786, "been dug in Derbyshire, on a spot called *Bonsall Moor*, in the neighbourhood of *Matlock.*" "A bed of iron-stone, about four feet in thickness, lies over the calamine, and the calamine is much mixed, not only with this iron-stone, but with *cawk*, lead ore, and Limestone."

* "Chemical Essays," vol. iv. 1786.

† "Cadmia Arabicus dicitur climia, quod quidam pronuntiarunt calimia, unde Græcis recentioribus χαλιμια interdum scribitur unde nostris Gallis calamina et lapis calaminaris" (Salmasius, De Homony, Hy. Sat. ccxxii.).

‡ "Germanis appellatur *blende* a *blenden* quia, cum falso speciem minera Saturninæ præ se sert, exinde oculos fascinet, vel iis præ se sert." (Pott, "De Pseudo-Galena," p. 106).

§ Plott's "Staffordshire." ‖ "Essay on Metals" and "Philosophical Transactions" for 1694.

"The calamine annually (1786) raised in Derbyshire amounted to about 1,500 tons a year. Sixty years previously they did not raise 40 tons a year. The Derbyshire calamine did not bear so good a price as that which is gotten about *Mendip*, in Somersetshire, the former being sold for about 40s., and the latter about 65s. or 70s. a ton before dressing. When thoroughly dressed the Derbyshire calamine may be bought for about six guineas, and the other for £8 a ton. There are many sorts of *blende*, or *black-jack*, which differ from each other not only in their external appearance, but in their internal constitution." Dr. Watson is not quite right in this. The zinc ore (blende, sulphide of zinc) varies in appearance from its sometimes containing silver, copper, or iron; but these are merely mixtures.

Dr. Watson says that Margraf, in 1746, by distillation, ascertained the quantity of zinc in different sorts of calamine to be as follows:—

	Parts.		Parts.	
Calamine from near Cracow	16	gave	2½	Zinc.
,, ,, England	16	,,	3	,,
,, ,, Holywell (Flint)	16	,,	7	,,
,, ,, Hungary	16	,,	2½	,,
,, ,, Breslaw	16	,,	4½	,,

Plott, in 1741, says: "This *semi-metal*, which at present is called zinc, was not known so much as by name to the ancient Greeks and Arabians. The name which it bears at present first occurs in Theophrastus Paracelsus, but no one as yet has been able to discover the origin of this appellation. A. G. Agricola* calls it *contrefeyn*; Boyle, *speltrum*; by others it is denominated *spiauter* and *Indian tin*. Albertus Magnus,† who died in 1280, calls calamine *golden marcasite*, and asserts that it approaches to a metallic nature.

Pott, in his book on zinc, speaks of the ores of zinc being yellow and red. Jungius ‡ says that in 1647 an ore of this kind, under the name of *tutenag*, is still brought from India, from which we may infer that for some time we had been indebted to the East for that metal. *Matthiolus*, *Agricola*, *Caneparius*, and others esteemed *calamine* to be a mineral in which there was no metallic substance.§ G. E. van Lohneiss, in 1617, says that zinc had for a long time been collected by fusion at Goslar. Erasmus Ebner appears to have been the first, about 1550, who first distilled the *cadmia* of Goslar. In 1721 Henkel tells us zinc may be obtained from *Lapis calaminaris* by means of phlogiston. In 1742 Anton van Swab extracted this metal from its ores by distillation, and in 1746 Margraf published a method of his own for effecting this.

A manufactory was established at Bristol, where zinc was obtained by *distillation per discensión*. Dr. I. Lawson is said‖ to have been "the first person who showed that *calamine* contained zinc. We have now on foot at home, a work established by the discoverer of this ore (?) which will probably make it very unnecessary to bring any zinc into England." Dr. Plott says, "To all this I shall only add one testimony more, from which it may appear that the English knew how to attract zinc from calamine before Mr. Van Swab taught the Swedes the method of doing it, though this gentleman, unless I have been misinformed, instructed the late *Mr. Champion*, of Bristol, either

* "De re Metallica."
† "In Libro Mineralium."
‡ "De Mineralibus."
§ Caneparius, "De Atram," pp. 12, 21.
‖ Supplement to "Chambers's Dictionary," published in 1753.

in the use of *black-jack* for the same purpose as calamine, or taught him some improvements on the methods of obtaining zinc from its ores. The testimony occurs in a dissertation of Henkel's on zinc, published in 1737. He is there speaking of the great hopes which some persons had entertained of the possibility of obtaining zinc from *calamine*; hopes, he says, which had been realised in England: 'ce qu'un Anglois arrivé depuis peu de Bristol, dû avoir vu réussir dans son pays.' * The manufactory of zinc was established in Bristol in the year 1743, when Mr. Champion obtained a patent for making it. About 200 tons were made annually at these smelting works. James Emerson began to make zinc at Henham, near Bristol, in 1777. The process of distillation was adopted, the metal being "condensed in small particles in water, and being re-melted, was formed into ingots and sent to Birmingham under the name of 'spelter'" (*Watson*).†

Calamine Earth had long been used in the manufacture of brass. Queen Elizabeth in 1565 granted to her Assay Master, William Humphry, a German, "a workman of great cunning and experience in the proper use of calamine, for the mixt metal called *latten*, or brass," a patent for the manufacture of this. In 1568 the Society of Mineral and Battery Works were actively making *latten*, and we find in the time of Henry VI. that his chaplain, John Bottwright, was made comptroller of all the mines, including *latten and lead*, within the counties of Devon and Cornwall. In 1639 a proclamation was issued prohibiting the importation of brass wire; and in 1650, *Demetrius*, a German, founded a brass work in Surrey, at the expense of £6,000.‡ Eight thousand men are said to have been employed in the brass manufactories near London and in Nottingham. Yet Sir John Pettus in 1670§ observes that these brass works were then decayed, and the art of making brass almost gone. In 1708 there were brass manufacturers in England who presented a memorial to the House of Commons, soliciting the protection of Parliament. They stated "that England by reason of the *inexhaustible plenty of calamine* might become the staple of brass manufactory for itself and foreign parts," and they argue that the continuing the brass works in England would occasion plenty of rough copper to be brought in. This would appear to show that but little copper was mined in this country at that period. Yet in 1720 we find Mr. W. Wood ‖ stating that "this nation could supply itself with copper and brass of its own produce sufficient for all occasions if such duties were laid on Foreign copper and brass as would discourage their importation." In 1783 a bill was passed in the House of Commons repealing certain statutes¶ and prohibiting "the exportation of brass, copper, latten, bell-metal, pan-metal, gun-metal," &c. In 1721, when various goods or manufactures of Great Britain were allowed by Act of Parliament to be exported free of duty

* This observation was first published in the fourth vol. of the "Acta Physico-Medica," Acad. Nat. Cur., 1737, but I have made the quotation from the edition of Henkel's works published at Paris, 1768, vol. ii. p. 494.

† "There is another substance which is denominated *spelter*, or spelter *solder*, by the braziers. It is composed of two parts of zinc and one of brass" (*Watson*).

‡ "Essay on Metal" (Brass), quoted by Dr. Watson.

§ "Fodinæ Regales."

‖ "State of the Copper and Brass Trade."

¶ Those of 28 Edward III. c. 5; 21 Henry VIII. c. 10; 33 Henry VIII. c. 7; 2 & 3 Edward VI.

—*lapis calaminara*—lead and several other articles are enumerated in the Act on which the duty was to be continued (*Watson*).

* Diego Ufano, in his "Artillery," published in 1614, gives the following statement of the metallic mixture used for the casting of cannon in Europe:—

Copper	160	100	100	100 parts
Tin	10	20	8	8 ,,
Brass	8	5	5	0 ,,

Bell-metal was made of one part of tin melted with four parts of copper, and zinc was added for small bells. A method for applying zinc upon hammered iron saucepans was introduced at Rouen about 1786. There was considerable prejudice against its use. A French physician, M. de la Planche, published a statement to the effect that he took the salts of zinc formed by vegetable acids in much stronger dose than the aliments prepared in *copper* vessels lined with zinc could have contained them, and he felt no dangerous effects.*

We find in Beckmann's "History of Inventions" the following note, appended by the recent editors to the article "Zinc":—

"Most of the zinc works in this country are situated in the neighbourhood of Birmingham and Bristol; a few furnaces also exist in the neighbourhood of Sheffield, among the coal pits surrounding that town. There is also one at Maestag, in Glamorganshire. The ores worked at Bristol and Birmingham are principally obtained from the Mendip Hills and Flintshire, those at Sheffield from Alston Moor." †

The production of zinc in the United Kingdom was as follows in 1881, when the returns made to the Mining Record Office were discontinued:—

No. of Mines.	Countries, &c.	Zinc Ore.	Metallic Zinc.
	ENGLAND.	Tons cwts. qrs.	Tons cwts. qrs.
4	Cornwall	7,792 17 3	3,507 15 0
4	Shropshire	196 17 0	107 5 0
—	Derbyshire	40 0 0	16 10 0
5	Cumberland	1,771 1 0	284 19 0
1	Yorkshire	35 5 0	15 17 0
	WALES.		
13	Cardiganshire	3,453 3 1	1,544 19 1
1	Montgomeryshire	1,414 0 0	610 0 0
5	Denbighshire	5,602 5 0	2,531 15 0
4	Flintshire	4,233 8 0	1,863 5 0
8	Carnarvonshire	792 8 2	291 10 0
2	Anglesea	2,305 12 1	632 9 0
1	ISLE OF MAN	7,567 10 0	3,480 0 0
2	SCOTLAND	325 0 0	61 10 0
50	Total	35,527 7 3	14,947 5 0

* Fourcroy's "Chemistry," vol. i.

† "A History of Inventions, Discoveries, and Origins." By John Beckmann. Translated by William Johnston. Fourth edition. Revised by William Francis, Ph.D., and J. W. Griffith, M.D. (Henry G. Bohn. 1846.) The zinc smelting works in 1881 were—

The Bagilt Zinc Company.	Joseph Thompson, Carlisle.
Vivian and Sons, Swansea.	Richardson & Co., Swansea.
Kenrick and Sons, Ruabon.	Villiers Company, Morriston, Swansea.
Zinc Works Company, Warrington.	Swan & Co., Mary-hill, Glasgow.
Dillwyn & Co., Swansea.	Swansea Vale Company, Swansea.

The Inspectors' returns for 1882 give zinc ore 32,538 tons, and metallic zinc 16,130 tons. These all go to prove that until recently the production of the ores of zinc—either the sulphide of zinc (*black-jack*), calamine (*carbonate of zinc*), or Smithsonite (*silicious oxide of zinc*)—has been small.

THE PRODUCTION OF ZINC ORE FROM THE MINES OF THE UNITED KINGDOM SINCE 1858.

Year.	Blende. Tons	cwts.	Zinc. Tons.	Year.	Blende. Tons	cwts.	Zinc. Tons.
1858	11,556	2	3,466	1871	17,736	10	4,966
1859	13,039	1	3,697	1872	18,542	12	5,191
1860	15,552	14	4,357	1873	15,969	1	4,471
1861	15,770	3	4,415	1874	16,829	16	4,470
1862	7,497	12	2,151	1875	23,978	8	6,713
1863	13,699	2	3,835	1876	23,613	8	6,641
1864	15,047	6	4,040	1877	24,405	16	6,833
1365	17,842	15	4,460	1878	25,438	2	6,309
1866	12,769	20	3,192	1879	22,199	19	5,554
1867	13,489	8	3,750	1880	27,547	15	7,162
1868	12.781	13	3,713	1881	35,527	7	14,947
1869	15,532	20	4,500	1882	32,538	14	16,130
1870	13,563	10	3,936				

The quantities of zinc ores produced in the several metalliferous districts of the United Kingdom in each of the five years ending in 1882 are shown in the following table:—

Average No. of Mines.	Counties.	1878.	1879.	1880.	1881.	1882.*
		Tons.	Tons.	Tons.	Tons.	Tons.
11	Cornwall	4,482	3,901	4,439	7,792	4,607
5	Shropshire	598	439	444	196	913
1	Yorkshire	5	—	—	35	109
1	Derbyshire	4	79	57	40	—
7	Cumberland	1,566	1,524	991	1,771	1,716
1	Durham	—	—	131	—	—
8	Cardiganshire	505	525	2,629	3,453	3,542
5	Montgomeryshire	2,217	1,927	1,581	1,414	1,528
3	Denbighshire	2,984	3,230	4,016	5,602	6,031
4	Flintshire	2,666	2,898	3,970	4,233	4,410
4	Carnarvonshire	504	667	728	792	617
2	Anglesea	—	—	—	2,305†	1,240†
5	Isle of Man	9,569	7,427	8,409	7,567	7,757
1	Scotland	235	76	109	323	59
1	Ireland	100	184	40	—	—

The quantity of calamine removed from the native deposits named cannot even be guessed at. It was regarded as a peculiar earth, not unlike alumina or magnesia, and its use was chiefly for the production of brass, although the

* Inspectors' returns.

† These returns consist of "*bluestone*," a compound ore, which, from analyses of 800 tons of this mineral by Mr. E. A. Parnell, of Swansea, gave the following results:—

Zinc	27·45
Lead	10·11
Iron	7·91
Sulphur	23·63
Arsenic	0·04
Copper	0·95
Silver	0·0263
Gold	Traces.
Alumina	2·98
Carbon	1·00
Silica	24·99
Loss	0·73
	99·8963

brass-makers do not appear to have been aware of the fact that they were dealing with a metallic compound. At one time, without doubt, considerable quantities of calamine were obtained. These were generally superficial deposits, and they have been for the most part worked out.

As the sulphide of zinc was generally found associated with copper or lead ores, and separated in the process of dressing, we have no satisfactory statement of the period at which the miners began to save the zinc ore (black-jack). That "Black Jack rides a good horse" is an old proverb arising from the fact that the dark zinc ore is frequently found above the ores of copper or lead. It may be safe to assume that zinc ore has been saved when found for at least one hundred years. The rapid increase in the production of zinc ore since 1858, and especially since 1874, is due to the numerous new applications which have been found for the metal zinc. We shall probably not be far wrong when we state our conviction that since the ore of zinc has been one of the products of mining industry, there has been raised and utilised not less than 2,500,000 tons, yielding to the zinc smelter about 600,000 tons of metallic zinc.

Our exports of British zinc, and our imports of crude zinc have been of late years as follows:—

Year.	British Zinc Exported. Tons.	Import of Zinc. Crude. Tons.	Import of Zinc. Manufactured Tons.
1876	5,673	29,466	14,719
1877	5,788	35,094	16,102
1878	6,665	32,750	16,207
1879	5,673	34,180	15,474
1880	8,023	33,409	16,648
1881	7,743	46,198	19,302

From this it will be seen that the zinc obtained in these islands has not been equal to supply the demands of our manufacturers.

IRON ORE.—There exists considerable difficulty in determining the quantity of iron ore which has been exhausted from the collieries and mines of this country. The chapter on the production of iron, and the historical sketch of the iron manufactures, includes nearly all the obtainable information. For 1881 the Inspectors' returns give of—

	Tons.
Ironstone from the Coal Measures	11,505,447
Iron ore from metal mines	3,596,747
" " Lincolnshire*	1,021,506
" " Northamptonshire*	1,270,544
" " sundry districts*	500,000
Total	17,894,144

For many years we have been exhausting our iron ore deposits at this enormous rate. The argillaceous ores of the Coal Measures are very nearly finished, and considerable tracts of country which have produced iron ores in considerable quantity now yield them very sparingly. We produce annually 8,144,449 tons of pig iron. To obtain this we are obliged to import from Foreign sources 2,450,000 tons of iron ore; and from pyrites imported chiefly from Spain, we separate 408,000 of "purple ore," which is separated in the process for obtaining the copper and silver they contain.

* The Inspectors of Mines could only obtain returns from mine-working. The ores procured from open workings or quarries were not, under the Mines Regulation Acts, to be returned to the Inspector.

Our pig-iron manufactures consume considerably more than 20,000,000 tons of iron ore annually.

MISCELLANEOUS MINERALS.—The following table will convey a sufficiently correct idea of the less valuable of the metalliferous ores and of some of the more important earthy minerals raised annually in these islands, according to the latest returns obtainable:—

		Produce in 1881. Tons.	Produce in 1882.* Tons	cwts.
1.	Pyrites (*Sulphide of Iron*)	43,616	18,550	0
2.	Do. (*Copperas lumps*)	5,370	6,847	0
3.	Gold (Ireland), 1 cwt. 1 qr. 27 lbs.			
4.	Blue Stone	2,305	1,246	0
5.	Silver Ore	6		7
6.	Nickel and Cobalt	63	38	0
7.	Wolfram	54	57	0
8.	Fluor-spar, &c.	372	144	0
9.	Ochre and Umber	7,966	5,101	0
10.	Manganese	2,884	1,548	0
11.	Arsenic	6,156	5,972	0
12.	Salt	2,298,220	2,185,002	0
13.	Barytes	21,313	22,294	0
14.	Coprolites and Phosphatic Nodules	31,500	No return	0
15.	Phosphate of Lime	60	50	0
16.	Gypsum	79,498	86,086	0

It is important, before we enter on the consideration of the future prospects of mining in this country, that a clear conception should be arrived at of the real value for the more recent years of the products of all our mines. A table has, therefore, been constructed which gives the amount of all the minerals of commercial, or industrial value, which have been raised in the United Kingdom during the five years ending with December, 1881. It has been felt necessary to include the coal, the iron ores of the Coal Measures, the salt, and clays, which form no part of the subject comprehended in this volume. The history of British mining has been traced, often imperfectly—but always with every desire to arrive at correct conclusions—from the period when the uncivilised Briton traded with the Phœnician sailors† until the year 1881, when the value of the mineral productions of these islands reached the enormous value of £90,860,487 sterling, as will be seen by the following tables, compiled from returns made to the Mining Record Office.

* 1882 is from the Inspector's Report, published 1883. It does not contain, in some cases, the total production.

† While these sheets have been passing through the printers' hands, a small work on "Celtic Britain," by J. Rhys, M.A., Professor of Celtic in the University of Oxford, has come into the author's hands, in which the following passages occur: "There is not a scrap of evidence, linguistic or other, of the presence of Phœnicians in Britain at any time, and the supposed proof (in the writings of Festus Avienus, a somewhat confused poet of the fourth century) that Himilco, in the flourishing times of Carthage, carried his voyage of discovery so far as this country, is exceedingly unsatisfactory."

Relying almost entirely on collections of coins, Professor Rhys writes: "A study of the early money of Britain also throws some light on the paths of intercourse between it and the continent. . . . . Thanet would seem to have been the island at *high tide* to which the tin of the west was brought in coracles by the natives for sale to the merchants who came for it from Gaul. The coasting voyage seems to have taken the former six days to make." The statement made by Diodorus is then given, and the *Iktis* is especially noticed as follows: "But the island itself can hardly have been St. Michael's Mount, as has sometimes been supposed, since that does not seem to have been an island at all in old times; nor was it the Isle of Wight, for that was never accessible on foot. In all probability it was no other than Thanet, which must formerly have corresponded completely to the description already cited."

The author feels it due to so eminent a Celtic scholar as Professor Rhys to state his opinion, directly opposed as it is to his own views. In the early pages of this volume the authorities are given, which appear to prove satisfactorily that the Phœnicians traded with, and ultimately settled in, Cornwall. Beyond this, the evidences of tradition,—which were more striking half a century since, than they are now, the existence of superstitions of evidently oriental origin,‡ the mining terms which unmistakably come from the East, and the connection through all historic time, of the Jews with tin-mining, appear conclusively to determine the question in favour of the views expressed in the Historical Sketch of this volume.

‡ See "Popular Romances of the West of England." By Robert Hunt, F.R.S.

THE MINERAL PRODUCTIONS OF THE UNITED KINGDOM.

Minerals, &c.	1877. Quantities.	1877. Value.	1878. Quantities.	1878. Value.	1879. Quantities.	1879. Value.	1880. Quantities.	1880. Value.	1881. Quantities.	1881. Value.
	Tons cwts.	£	Tons cwts	£	Tons cwts.	£	Tons cwts.	£	Tons cwts.	£
Coal	134,610,763 0	47,113,767	132,607,866 0	46,412,753	134,008,228 0	46,902,879	146,818,622 0	62,395,414	154,184,300 0	65,528.327
Iron Ore	16,692,802 0	6,746,668	15,726,370 1	5,609,507	14,379,735 0	4,962.434	18,026,049 16	6,585,806	17,446,065 6	6,201,068
Tin Ore	14,142 6	572,763	15,045 14	530,737	14,665 0	586,608	13.737 11	673,142	12,893 3	697,444
Copper Ore	73,141 0	262,270	56,094 0	201,434	51,032 0	177,328	52,118 0	190,667	52,556 1	190,057
Lead Ore	80,850 0	1,123,952	77,350 0	801,428	66,877 0	688,740	72,245 0	816,368	64,702 5	656,725
Zinc Ore	24,405 16	86,151	25,438 2	80,565	22,199 0	81,531	27,547 15	90,545	35,527 7	110,043
Iron Pyrites	43,948 10	28,225	29,867 15	19,099	20,275 0	11,835	31,708 2	23,004	43,616 14	30,033
Arsenic	4,809 4	30,420	4.991 10	26,900	5,492 10	34,180	5 738 5	43,498	6,156 8	45,070
Manganese	3,038 14	7,958	1,536 4	3,120	816 8	1,515	2,839 1	5,601	2,884 0	6,441
Bismuth	8	15	—	—	1	14	—	—	—	—
Cobalt and Nickel	27 4	242	98 18	616	116 11	883	49 3	297	63 14	310
Gold Ore	—	18	—	—	—	—	2 0	25	1 10	18
Silver Ore	142 15	927	94 9	5	27 19	621	14 8	2,961	5 19	358
Uranium	2	11	8	44	5	41	—	—	—	—
Wolfram	15 0	150	10 0	100	13 0	120	2 0	8	54 7	544
Fluor-spar, &c.	220 3	36	391 17	133	1,264 16	422	458 2	350	—	—
Ochre and Umber	5,074 3	4,488	4,414 17	4,038	3,973 12	3,436	6,126 9	11,512	7,966 9	12,286
Clays (Fine and Fire)	2,961,155 0	592,231	2,711,486 0	677,871	2,888,489 0	717,143	3,062,544 0	1,635,650	2,401,421 0	1,200,210
Salt	2,735,001 0	1,504,250	2,682,930 0	1,344,465	2,558,368 0	1,279,184	2,645,000 0	1,322,500	2,298,220 0	1,149,110
Barytes	21,056 7	28,948	22.435 16	36,606	19.349 18	21,068	18,476 19	13,383	21,313 11	23,894
Calc-spar	2,351 2	625								
Coprolites, &c.	69,006 0	200,000								
Oil Shales	123,558 0	61,779	778,029 0	512,200	525,950 0	262,975	—	275,500	—	349 500
Gypsum	73,908 0	22,172								
Sundries	—	10,000								

TOTAL VALUES OF ORES RAISED.

Year	£	s.	d.	Year	£	s.	d.
1877	58,398,071	10	5	1880	74,094,638	17	5
1878	56,246,495	10	8	1881	76,201,695	2	2
1879	55,733,967	19	10				

METALS OBTAINED FROM THE ORES PRODUCED IN THE UNITED KINGDOM.

METALS.	1877.		1878.		1879.		1880.		1881.	
		£		£		£		£		£
GOLD	143 ozs.	636	702 ozs.	2,848	447 ozs.	1,790	10 ozs.	39	4½ ozs.	18
PIG IRON . . .	6,600,664 tons	16,191,236	6,154,992 tons	16,154,922	5,995,337 tons	14,988,342	7,749,233 tons	19,373,082	8,144,449 tons	20,361,122
TIN	9,500 „	695,162	10,106 „	663,080	9,532 „	689,163	8,918 „	813,767	8,615 „	830,680
COPPER	4,486 „	340,067	3,952 „	271,042	3,462 „	222,507	3,662 „	253,277	3,875 „	263,500
LEAD	61,403 „	1,262,600	58,020 „	972,491	51,635 „	756,489	56,949 „	953,895	48,587 „	728,805
ZINC	6,281 „	136,612	6,309 „	123,025	5,554 „	95,806	7,162 „	123,524	14,947 „	252,608
SILVER FROM LEAD .	497,375 ozs.	113,950	397,471 ozs.	88,296	333,674 ozs.	70,905	295,518 ozs.	63,015	308,398 ozs.	67,140
SILVER FROM ORE .	4,069 „	927	27,648 „	6,223	3,000 „	620	1,765 „	382	1,650 „	360
OTHER METALS— *Estimated Value* .	—	1,750	—	1,125	—	1,000	—	17,500	—	—

TOTAL VALUE OF METALS OBTAINED.

	Metals.	Coal.	Earthy Minerals, &c.	Total.
	£	£	£	£
1877 . . .	18,742,960 . . .	47,113,767 . . .	2,424,679 . . .	68,281,406
1878 . . .	18,283,124 . . .	46,412,753 . . .	2,643,404 . . .	67,339,281
1879 . . .	16,835,622 . . .	46,902,879 . . .	2,333,769 . . .	66,072,271
1880 . . .	21,582,501 . . .	62,395,414 . . .	3,539,635 . . .	87,517,550
1881 . . .	22,514,508 . . .	65,528,327 . . .	2,817,652 . . .	90,860,487

It must not be forgotten, that mineral treasures have been continuously excavated from our rocks and the alluvial deposits for more than 2,000 years, consequently a considerable exhaustion of "the corpus" must have been the result.

The great Linnæus wrote: "Stones grow. Plants grow and live. Animals live and move." Let it be distinctly understood, in opposition to this great authority, that *stones do not grow.* They may increase in size by the accretion and aggregation of similar particles together, but *growth* is the increase of size by the addition of matter under circumstances which involve in some form, or other, chemical change. There has not been, therefore, any *growth* of any mineral during the 2,000 years which have elapsed since man brought his efforts to bear on the search for mineral treasures in the superficial crusts of our planet.

In the caverns of the Earth—in the fissures of the rocks—through which water holding mineral matter in solution has been for ages percolating, crystallization has been active, and beds of mineral matter have been formed. This has been effected in many cases by precipitation from water, of matters held in mechanical suspension, and in other cases by the crystallization of salts, held in solution under the influence of oxidising agents.

We certainly have occasional evidences of the decomposition of a mineral lode in one place, leading to the formation of soluble salts, which have been carried by the circulating fluids to another place of repose, and Nature has produced, by the influences of silently operating forces, geometric forms of exquisite work and beauty.

We find some varieties of copper ore which are evidently of recent origin, and instances have occurred in both Cornwall and Wales in so-called exhausted lead mines, where the abandoned levels have been filled, or at all events, the walls lined with the phosphate, arseniate, and other ores of lead.

While admitting the fact that minerals of comparatively recent origin may be forming at the present time, we must not fail to impress upon our readers that man has removed vast masses of metalliferous ores with rapidity, while the reproduction by Nature of a few rare minerals has proceeded with infinite slowness.

Wallace* draws attention to the removal of lead ore from the veins in Alston Moor. "Undoubtedly," he says, "many of the portions of veins contained at some former geological period much richer deposits of lead ore than when first laid open by mining operations." Other evidences might be brought forward to show that new deposits have been formed before man began to penetrate the surface, and since, with avaricious zeal, he has laboured to find the buried wealth. But these changes would never reproduce in the fissures of the rocks one-millionth part of the metalliferous ores which man has removed.

PYRITES.—The production of pyrites (sulphur ores, mundic, arsenical ores) from the mines and collieries of the United Kingdom has been comparatively unimportant. It may, however, be expected—now that the value

* "The Laws which Regulate the Deposition of Lead Ore in Veins." By William Wallace.

of Pyritic Ores is becoming better understood—that more attention will be paid to the preservation of the minerals of this character.

			£	s.	d.
In 1878	29,867	tons were produced of the value of	19,099	5	10
1879	20,275		11,835	13	3
1880	31,708		23,004	9	5
1881	43,016		30,033	6	5
1882	25,403		14,459	0	0
	6,847		3,594	0	0

The imports from 1877 to 1881 of pyrites of iron and copper will show—

	Norway.	Portugal.	Spain.	Other Ports.	Total.	Total Value.
	Tons.	Tons.	Tons.	Tons.	Tons.	£
1877	8,564	149,562	498,977	22,209	679,312	1,643,614
1878	5,773	136,705	419,561	12,318	579,261	1,336,047
1879	8,485	82,529	374,505	15,873	481,392	1,050,545
1880	10,952	166,519	463,199	8,684	658,047	1,522,724
1881			—	—	542,378	1,202,281

The real value of these sulphur ores will be apparent when we state that in addition to the sulphur and iron, the ores imported in 1881, gave of—

	1881.		1882.	
Fine Copper	14,000	tons	15,300	tons.
Silver	258,463	ounces	400,000	ounces.
Gold	1,490	,,	1,500	,,

The copper was obtained from "*burnt ore*," that is, from the residuum after the sulphur had been separated by calcination. The principal portion of the *silver* and the whole of the *gold* was got from copper liquors by Mr. Claudet's patent process. A small portion of the silver was separated from copper precipitate by the manufacturers of sulphate of copper.

MANGANESE.—The principal manganese ores obtained in these islands are—

		Manganese.	Oxygen.
1.	Pyrolutite—Cornwall, Warwickshire	63·3	31·7
2.	Manganite—Cornwall, Devonshire, Somersetshire, Warwickshire, Scotland, Ireland	Oxide of Manganese. 89·90	
3.	Psilomelane — Cornwall, Devonshire, Cumberland, Scotland, Ireland	69·80 and	81·8
4.	Wad—Devonshire, Derbyshire	63·60 ,,	66·5

The quantities obtained have been—

—	Quantities.		Value.			Imports.	Value.
Year.	Tons	cwts.	£	s.	d.	Tons.	£
1877	3,038	14	7,958	1	6	13,176	67,878
1878	1,586	4	3,120	17	2	9,820	40,225
1879	816	8	1,515	10	0	12,172	45,873
1880	2,839	1	5,601	7	0	16,085	67,070
1881	2,884	1	6,441	5	0	18,748	71,140
1882*	1,548	5	3,907	0	0	29,760	102,267

The recent discovery of very extensive beds of manganese in America must tend to the reduction in value of the small production of this country.

In concluding this section of our inquiry, it may not be out of place to draw attention to the fact that the deepest tin mine in England is still the richest. This appears to show that probably metalliferous veins, especially

* Inspectors' returns including pyrites (brasses) from the Coal Measures and copperas lumps.

those containing tin, extend to a far greater depth than has yet been explored. At the present time, 1883, the tin lode at Dolcoath at the depth of 420 fathoms is seven fathoms wide, yielding a very high percentage of black tin.

The following account of this remarkable mine was given by the manager, Captain Josiah Thomas, on the visit of the Polytechnic Society in 1882:—

"Dolcoath was worked for several years in the last century, and was suspended in 1787. The present company recommenced working her in 1799.

"The sett is about three-quarters of a mile in length, on a line with the lodes, which have a direction about east and west. About 70 miles of level have been driven on the various lodes. The mine is now above 400 fathoms deep (half a mile). The total money paid out of the adventurers' pockets from the commencement of the present company was £45,000. They have raised three and a half million pounds' worth of copper, two million pounds' worth of tin, and thirty thousand pounds' worth of arsenic, silver, &c., the total produce being worth over £5,500,000 sterling. The dividends during the present workings of the mine amounted to upwards of £560,000, of which more than £266,000 had been divided during the past fourteen years. They have thirteen steam-engines at work, and one thousand two hundred people employed. They were now raising one hundred and fifty tons of stuff a month. They are not raising copper. The profits are now between £30,000 and £40,000 a year, or nearly a profit per annum, equal to the whole outlay ever made on the mine."

There is every reason for supposing that the conditions found at Dolcoath will prevail over the district shown in the map of the mineral veins and cross courses, in the district of Carn Brea and Illogan, including Camborne and Redruth. It would therefore appear to be well deserving of careful consideration whether it might not be found profitable to penetrate still deeper into the Earth in some of the stanniferous districts of Cornwall and Devonshire. The additional cost of sinking the mines might be met by a rigid economy, and by the introduction of machinery, for boring, for ventilating the mines, and for lowering and raising the miners.

There have been at work in this country during the last ten years the following number of tin mines. The variations in produce relatively to the number of mines worked demand especial attention:—

		Tin Ore.			Tin Ore.
1872	162—producing	12,299 tons.	1877	98—producing	14,091 tons.
1873	215 ,,	14,884 ,,	1878	90 ,,	15,045 ,,
1874	230 ,,	14,039 ,,	1879	86 ,,	14,665 ,,
1875	183 ,,	13,995 ,,	1880	91 ,,	13,737 ,,
1876	135 ,,	13,688 ,,	1881	95 ,,	12,900 ,,

It is desirable to bear in mind that little or no tin can be expected to be obtained in the future from alluvial deposits. Nearly all the veins producing tin, at comparatively shallow depths, have been carefully explored, and for the most part exhausted. The evidences given above, however, promise the production of tin in large quantities, at depths considerably beyond those to which our miners have yet penetrated.

CHAPTER II.

ON THE LIMITS OF THE METALLIFEROUS ZONE.

THE "sermons in stones" which are written on the geological tablets of the book of Nature have been the subjects of study to many of the most intellectual minds which adorn the lists of Science.

A geological section—carefully drawn from the most recent observations of some of our best field geologists—instructs us that the formations of which we have any exact knowledge are the—

			Feet.
TERTIARY, OR CAINOZOIC	Including the Epochs of the PLIOCENE, MIOCENE, EOCENE		have a thickness of 2,750
		Feet.	
SECONDARY, OR MESOZOIC	The Cretaceous	3,850	
	The Oolitic, or Jurassic	4,000	12,850
	The Triassic	5,000	
PRIMARY, OR PALÆOZOIC	Carboniferous	20,000	
	Old Red Sandstone and Devonian	10,000	
	The Silurian	40,000	90,000
	The Cambrian	20,000	
	Laurentian	*unknown*	
		Total thickness	10[illegible],600
			Or nearly twenty miles.

Man has not yet penetrated a mile in perpendicular depth. The greatest depth reached by the metalliferous miner is at Dolcoath mine, where he has reached 2,520 feet, or nearly half a mile, and at the Rosebridge Colliery, near Wigan, the works have reached a yet greater depth. Consequently it is only under some special condition that we are enabled to determine the vertical thickness of the known rocks. By the operation of some subterranean forces, acting through countless ages, a series of disturbances have been effected, by which the beds which are the lowest in true geological position have been lifted, or tilted, until they appear on the surface of the Earth. In some instances this uplifting has been due to vast and sudden catastrophes, in others to slow and silent movements, by the influence of mechanical powers acting at great depths. We have to deal with these phenomena no further than they explain those mutations which enable us to rearrange the rocks in their true order, from the most recent alluvial deposits, down to the Laurentian rocks, which are, to us, at present the foundation-stones of our geological system.

The conditions of mineral lodes, and statements of the more important hypotheses by which the deposition—whether in beds or in fissures—of the metalliferous ores are explained, have been brought under notice.

The mineralogical modifications of the various rocks in our metalliferous districts must now claim our earnest attention. As long since as 1814 the

Rev. J. J. Conybeare* pointed out the general difference between the rocks in North Devon, and those in the south of that county, and in Cornwall.

In 1823 the same author commenced a detailed account of the Slate Rocks of Devon and Cornwall, which, however, he left incomplete.†

Mr. Conybeare adopts the following divisions:—

I. *Metalliferous*, or, more strictly speaking, stanniferous and cupriferous Slate, including various porphyritic and felspathic rocks (*Elvans*), and occasionally Greenstone, which he terms the *inferior* Slate.

II. *Slate*, called *superior Slate*, containing no Elvans, but abounding in Greenstones, especially its obscurer varieties, and in dark-coloured Limestones. *Sparingly metalliferous*, containing no Tin, but more productive of Lead than the *inferior* Slate.

III. *Stratified Rock*, exhibiting the general character of a conglomerate or Sandstone, alternating with *tender* Slate, and occasionally associated with coraline or shelly Limestone. It contains *no metallic veins*, and few, if any, rocks of the Greenstone kind. "This rock might, perhaps, be regarded as forming the upper part of the *superior Slate*, and both would probably by most geologists be termed *Grauwacke*." ‡

Dr. Boase in 1831§ adopts the divisions of Mr. Conybeare, but proposed to name the Cornish Slates as *Porphyritic* and *Calcareous* instead of inferior and superior. "Most of the rocks of the calcareous series appear to be referable to the older portions of that class which is intermediate between primary and secondary, commonly known by the name of *Transition*." We have already dealt with the rocks of our mineral districts, and, at page 216, a section is given which shows the character of the metalliferous and non-metalliferous beds.

De la Beche remarks ‖ that "the Cornish miner prefers a Granite or Elvan which is to a certain extent decomposed. The particular character of the various kinds of schistose rocks, and the harder beds associated with them, is also carefully noted, and from experience some kinds . . . . are known to carry more ore than the others, while some again are regarded as unfavourable."

Mr. J. Carne states that when the copper lodes in Gwennap intersect the *Red Beds* they become unproductive, an immediate change taking place when they pass beyond them into another state. "In most lodes the miners have their favourite kind of rock, or *country*, so that the whole tendency of their experience goes to show that particular mineral structures, other circumstances being the same, are more favourable to the occurrence of the ores sought than others." Mr. Carne further observes,¶ "that in Godolphin mine the lodes were rich in the *Killas* (argillaceous Slate) when it was of a bluish-white colour, but poor when it was black. In Poldice and Wheal Fortune the lodes in the Killas continued productive until they entered a

* "Memoranda relating to Clovelly." ("North Devon Geological Transactions," vol. iii. 1814.)
† "On the Geology of Devon and Cornwall." ("Annals of Philosophy," 1823.)
‡ Grauwacke. In De la Beche's Report on the Geology of Cornwall, Devon, and West Somerset, at p. 38, will be found some remarks on the use of this name. See also page 217 of this volume.
§ "Contributions towards a Knowledge of the Geology of Cornwall." ("Transactions of the Geological Society of Cornwall," vol. iv.)
‖ "The Geological Observer," p. 670.
¶ "Transactions of the Geological Society of Cornwall," vol. iii. p. 81. 1827.

stratum of blue hard Killas which *cut out* the richer. In Wheal Squire the copper lodes were very productive when in the soft light-blue Killas, but a stratum of hard black variety underlying (*dipping*) rapidly, met one lode at a depth of 44 fathoms, and the other at 120 fathoms under the adit, and at these levels both became poor. At Penstruthal copper mine the lode had been tried unsuccessfully at various times in parts where the Granite was *hard*; but trial being made where the rock was soft, it became one of the most profitable mines in Cornwall."

That these conditions prevail in other countries is certain. One authority only will, however, be quoted; that of M. Fourney. He states that commonly in Upper Hungary the richest copper ores are found in the *fine Clay-Slate*; that in Saxony the silver ores occur in Gneiss; that in the Hartz certain ores are intimately connected with *Grauwacke*. At Andreasberg the veins, which pass from argillaceous Slate into flinty Slate, lose their riches in the latter rock. The veins of Kongsberg, Norway, are sterile in Mica Slate, and become productive in beds known by the name of *Faalbander*.

In Derbyshire, where the same fissure not only passes through the Mountain Limestone, often with its associated igneous rocks, but also across the surrounding and higher accumulations of *shales* and Sandstones, the lead ore (sulphide of lead) keeps generally, though not altogether, to the Limestone series, and appears most prevalent in the upper part of it. At one time the Derbyshire miners thought that lead veins did not traverse the *Toadstones* or *blackstones*, so unproductive are they. It is now, however, known that *Rake Veins*—which are true fissures—pass through those igneous rocks as well as through the Limestones, the ore being absent where the igneous rocks constitute the walls of the vein.

Sir Henry de la Beche writes*: "Among the Limestone beds themselves some are considered more favourable, as walls to the vein, than others, and certain of them, in which much carbonate of magnesia occurs, are disliked and looked upon as somewhat unfavourable. Though the veins are known to be often continued into certain shales, not unfrequently black, and containing much carbonaceous matter above the Limestones, and though those *shales* have occasionally *borne*—as the term is—a fair amount of ores; looking at the district generally, this is the exception; and it is a still greater exception when the Sandstones surmounting these shales contain any appreciable amount of ores, though a fissure may have traversed all these various rocks, arranged as beds, and have been open to solutions of a similar kind at the same time. Taken as a whole, the upper part of the Mountain Limestone series in Derbyshire is the *most metalliferous*, and in it certain beds appear more favourable for the occurrence of the ores of Lead than others."

Of the occurrence of the ores of Lead, in spaces between beds, which were open when they, and the other contents of such cavities, were accumulated, those at Fawnog, near Mold, Flintshire, are striking examples. Mr. Warington W. Smyth informs us that after an unprofitable search for Lead in the shallow workings between the Carboniferous Limestone and its covering of arenaceous rocks known as Millstone Grit, it was discovered that ore was abundantly distributed in a flat or *streak of ore* between the rocks.

* "The Geological Observer," p. 682.

To quote De la Beche again: "Not only are certain minerals, including the ores of the useful metals found in a fissure, more frequently adhering to, or accumulated near, particular rocks, or modifications of the same rock . . . . but also in some districts, where more ores than one occur in sufficient abundance to be profitably worked, so that the ground is well explored, fissures in given directions are observed to contain certain of those minerals more than others."

Mr. W. W. Smyth remarks: "The metalliferous district of Cardiganshire and Montgomeryshire is a tract of land . . . . formed exclusively of Clay-Slates, and Gritstones correspondent with or underlying the lowest beds described by Sir R. Murchison in his 'Silurian System.'"* And again he continues: "The presence of ore cannot here be directly ascribed to the proximity of Granites or Porphyrites, since this happens to be the only large portion of the Slaty rocks of Wales, in which not a vestige of any rock of igneous origin is met with. Moreover, whilst their occurrence in the bed of only one epoch renders it impossible to fix their *geological age*, the various direction of the lodes gives no clue towards the determination of their relative age."

The great mining districts of Alston Moor and those of the northern counties are thus concisely described by Mr. William Wallace:—

"The groups of the newer Palæozoic rocks, consisting of the Mountain Limestone, Millstone Grit, Coal Measures, and New Red Sandstone, repose conformably on the Old Red Sandstone; and in the North of England, excepting the last, they all pass into each other by regular alternations, and are well developed in the tract of country, about 60 miles broad, lying on the West side of a line drawn from Nottingham to Berwick-on-Tweed, a distance of about 200 miles." This comprehends the mineral district of Northern England, which has been for a long period remarkable for its production of lead ores. Mr. W. Wallace, in his "Mineral Deposits," urges an hypothesis, that all the lead mines in Alston Moor of a productive character have been found *above* the present watershed of the country. There are a few exceptions to this rule, where profitable lead-mining has been carried on in the Lower Limestone stratum. This hypothesis, however, lends its support to the fact, that the deposits of lead ore do not extend to any considerable depth, and, as a rule, the large masses of galena have been discovered at comparatively small depths from the surface.

It would not be difficult to increase considerably the evidence which goes to show that certain rocks are generally metalliferous, whilst others are almost invariably not so, and that the geological situation of the rocks appears to determine their metal-bearing character. The occurrence of detrital tin in the valleys, on the modern seashores, and rivers certainly proves the existence of large tracts of land which have been removed by denudation. Tin lodes which we detect in our mines must have extended originally into the rocks which have disappeared by denudation. All the tin and all the gold (at one period the precious metal without doubt occurred in large quantities) found in the tin streams must have been derived from these

* "On the Mining Districts of Cardiganshire and Montgomeryshire." By Warington W. Smyth, M.A., F.R.S. ("Memoir of the Geological Survey of Great Britain.")

veins, which have been through ages gradually worn down through natural causes. The tin lodes of Cornwall have been generally found near the surface, as at Dolcoath, Tresavean, and numerous other mines. Copper has been discovered at greater depths below the tin, showing that some remarkable mutations have occurred. Whatever hypothesis may be adopted, it is certain that a new set of conditions must have taken place to produce in the same fissure, a deposition of copper ore below that of tin. We have not the remotest idea of the character of the change; it would be, therefore, idle to venture on any speculation respecting it. The lode in Dolcoath mine, as already stated, shows yet another remarkable change at a still greater depth. Below that portion of the lode containing the copper pyrites, a rich deposit of tin has been again formed, and this stanniferous vein continues increasing in its productive state to the extremest depth explored. An idea prevailed amongst the old tin miners that Granite was a rock which was not conducive to the deposition of copper ore in its fissures. De la Beche writes: "Not many years have elapsed since it was held good doctrine that no copper ore, *in profitable quantity*, could be found eastward of Truro Bridge, and the existence of such mines as Crinnis and Fowey Consols have been, would have been considered highly improbable, and consequently it would have been thought a wanton waste of capital to have embarked in the search for copper in that neighbourhood; yet a very ordinary amount of geological research would make it appear that the conditions which accompany many of the lodes near St. Austell are very similar to those in the great cupriferous district of Gwennap."

The occurrence of tin and copper in Granite and in Elvan, regarding them both as rocks which have been to a greater or a less extent subjected to igneous action, and to have been forced through the superincumbent strata, may admit of some explanation. These rocks, when in a semi-fluid or plastic state, were forced through the Slates or Sandstones, when these were yet thoroughly impregnated with metalliferous matter. This would naturally find its way into the Granite or the Elvan, and either in the fissures or in the solid mass of these rocks during the slow process of consolidation and crystallization. The metalliferous minerals found in these rocks must, therefore, be regarded as belonging to the age of the rocks into which, or through which, they have been forced.

This is also perceived to be the case with the small metalliferous veins of Derbyshire, which are near the *Toadstones* of that county.

It is not desirable in the present state of our knowledge to extend this portion of our inquiry, especially as the space at disposal has become very limited.

All the evidence given tends to prove that the metalliferous ores which are useful to man have been discovered in a certain class of rocks of a well-marked character. In the *Tertiary* or *Cainozoic* rocks there is an almost entire absence of metalliferous minerals excepting iron, and the ores of this metal have been clearly introduced by infiltration.

In the *Secondary* or *Mesozoic* formations a similar set of conditions prevail. In many of the strata, very extensive deposits have been found and worked. But the discovery of the ores of any of the other metals must be regarded as unusual and, generally, accidental.

In the *Primary* or *Palæozoic* rocks we find the Permian group, embracing the Dolomitic or Magnesian Limestone rocks, and the New Red Sandstone, and the New Red Conglomerate becoming more and more metalliferous with depth. The Carboniferous and Mountain Sandstone, with its Coal and Sandstone, its carboniferous Slates, all are, more or less, productive of the more especially metalliferous ores; the same may be said of the Devonian group, with its various modifications of the Old Red Sandstone series.

We have seen that in the Silurian group of Wales lead and copper have been found. We desire to quote a passage from Sir R. I. Murchison's "Siluria,"* which, although it is especially directed to the occurrence of gold, bears distinctly on the question relating to the depth to which metalliferous deposits may be expected to extend: "In conclusion, let me express my opinion that the fear that gold may be greatly depreciated in value relatively to silver—a fear which may have seized upon the minds of some of my readers—is unwarranted by the data registered in the crust of the Earth. Gold is, after all, by far the most restricted, in its native distribution, of the precious metals. Silver and argentiferous lead, on the contrary, expand so largely downwards into the bowels of the rocks as *to lead us to believe that they must yield enormous profits to the skilful miner for ages to come*, and the more so in proportion as better machinery and new inventions *shall lessen the difficulty of subterraneous mining*.†

"It may, indeed, be doubted whether the quantities both of gold and silver procured from regions unknown to our progenitors, will prove more than sufficient to meet the exigencies of our augmenting commerce and luxury. But this is not a theme for a geologist, and I would simply say that Providence seems to have originally adjusted the relative value of these two precious metals, and that their relations having remained the same for ages will long survive all theories. Modern science, instead of contradicting, only confirms the truth of the aphorism of the patriarch Job, which thus shadowed forth the downward persistence of the one and the superficial distribution of the other, 'Surely there is a *vein* for the silver. . . . The Earth hath *dust* of gold.'"‡

It is greatly to be regretted that the observations of the miners made through long centuries have not been recorded. Miners are usually excellent observers, but it is rare indeed to find a practical miner who has left a note either for his own guidance or as a direction for his children. The experience of the aged miner has perished with him, and his son has to begin exactly where the father began before him; consequently the advance made in our knowledge of subterranean phenomena has been exceedingly slow and very limited. Looking, however, at the evidence afforded, most of which has been carefully selected, and it is hoped clearly given in this volume, it all points to the conclusion that the deposition of the metalliferous ores —whether we regard them as being produced under either of the following conditions—belong to certain well-defined geological epochs.

* "Siluria: the History of the Oldest known Rocks containing Organic Remains." By Sir Roderick Impey Murchison, D.C.L., F.R.S., &c. 1854.

† A note is given, which says: "A recent report from Colonel Lloyd . . . shows to what an enormous extent silver may be extracted from Copiapo and other South American mines. This was, indeed, the view taken long ago by Humboldt."

‡ The Book of Job, chap. xxviii.

1. *As of Aqueous Origin*—that is, produced by water holding metallic salts in solution percolating through the stony beds, or flowing through, and filling, the fissures,—be they large or small,—already formed in the rocks.

2. *As due to high Subterranean Temperature*, as they appear to be in many of the mining districts of California, where hot springs rise charged with Silica; and as the quartz is deposited on the sides of the fissure, it is found that gold and other metals precipitate at the same time.

3. *As due to the Ejection of Vapours*, holding the metals, or salts of the metals, in solution, or in mechanical suspension.

It appears that all the metalliferous deposits must be limited to the epochs extending from the Silurian period to the deposition of the Permian group. So far as the newer rocks are concerned, the practice, based on the experience of the miners of all countries, has led to the conclusion that, except for detrital deposits, or for iron ores, it is useless to search in any district the rocks of which do not belong to the Palæozoic formations. Whether mineral veins are to be found below the Silurian rocks is questionable. Sir R. Murchison has the following remarks on this question. He was evidently thinking of the occurrence of gold when he wrote them —but they involve the consideration of the presence of copper and lead in the Silurian rocks: "In the *vicinity* of some igneous rocks these schists and calcareous flagstones have been filled with mineral veins. Besides ores of lead and copper, it will be shown that rocks of this age were rendered partially auriferous in Wales, and largely so in other countries. One of the tracts in the original Silurian region, where the Llandeilo formation is most metalliferous (*lead veins*), is that lofty and rugged district of Shropshire, which lies around the village of Shelve and the Corndon mountains, and which extends from the west of the Stiperstones into Montgomeryshire."

If the principle of the percolation, and circulation of water is admitted to be a law essential to the deposition of any of the metallic ores, it is quite certain that no such circulation could go on at depths where the temperature was as high as that of boiling water. Before 212° were reached the aqueous fluid would begin to circulate, the heated portion rising through the colder fluid; and during this circulation the attraction of aggregation, or of some analogous force—as, for example, the crystallogenic force—would be brought into action, and the solid deposits formed on the sides of the fissures.

Sir W. Grove remarks, in his "Correlation of Physical Forces": "There is scarcely any doubt that the force which is concerned in aggregation (of crystals) is the same which gives to matter its crystalline form; indeed, a vast number of bodies, if not all, which appear amorphous, are, when closely examined, found to be crystalline in structure. We thus get a reciprocity of action between the force which unites the molecules of matter and the magnetic force, and through the latter the correlation of the attraction of aggregation with the other modes of force may be established."

This passage, read in connection with what has been already said in reference to the electricity detected in mineral lodes, will convey to the thoughtful mind a tolerably clear idea of the phenomena which, slowly, silently, but continuously, is ever active in the dark recesses of the rocks.

It must be remembered that, supposing metallic matter to be held in

suspension or solution in super-heated steam, or in the vapours arising from the seat of volcanic power, that this would not be deposited until the fluid, the gas, or the vapour had reached a stratum the temperature of which was considerably reduced. Therefore the heat of the rocks *in situ* regulates to a great extent the probability of the formation of metalliferous deposits. It is not improbable that mineral lodes may be formed under either of the three conditions named; but it appears evident that the physical conditions must determine the existence of definite strata, which may be regarded as a strictly *metalliferous zone.*

The extreme depths to which the Cambrian and Laurentian rocks reach, appear to place them below the region where it is possible that metalliferous minerals can be formed. We have already mentioned the production of pyritic crystals in furnaces; but it is thought that these can only be formed where the temperature has been considerably reduced. It is not probable the labours of the miner will ever enable him to penetrate to the subterranean recesses. We have therefore to be satisfied with hypotheses which conform the most closely to the laws which we gather from our observation of matter on the surface of the globe. The arguments, based on long experience, and careful observation, appear to prove that the lowest known rocks are below the influences which are necessary to the production of mineral wealth. The conclusion to which, therefore, we are led is that profitable mining can only be carried on within the limits indicated, which we may especially characterise as the METALLIFEROUS ZONE.

CHAPTER III.

THE OCCURRENCE OF ORES AT GREAT DEPTHS; OR IN NEW DISTRICTS.

THE preceding chapters will have rendered it evident that the constantly increasing discovery of metal mines in all parts of the world, and the consequent supply of the requirements of our manufactures by importations from our Colonies and Foreign countries, must keep down the prices of the metals.

All our mines are rapidly getting deeper, and becoming, at an increasing ratio, more expensive to work. There are, therefore, two elements which materially affect the future of British mines—

1. Are we enabled by our present knowledge to say if it is probable that our mineral treasures will extend to any considerabe depth beyond that which we have now reached?

2. Are there any districts unexplored from which any largely increased supplies are to be expected?

Those who have read the preceding pages cannot fail to have arrived at the conclusion, that all the evidence given strongly supports the view that the production of tin from detrital deposits in Cornwall and Devonshire is almost at an end. The "Stream Tin," as it is still commonly called—obtained from washing the deposits in estuaries, rivers, and foreshores—is now derived, principally, from the dressing-floors of tin mines. Under the most favourable circumstances, it has been shown that fine particles of black tin are constantly being carried away by the waste waters flowing from the mines. The necessity for using clean water for the final operations of dressing has been already insisted on. Yet even when this is strictly attended to, minute particles of black tin (tin ore), adhering to atoms of Clay-Slate, or other rock, will float away, and are eventually deposited with the mud in rivers, or estuaries, or shores. By the influence of air and water—and especially by the changes of temperature—the tin eventually separates from the earthy matter, and in the still water, slowly falls in obedience to the laws of gravity.

By improvements in the dressing processes no doubt much tin may be saved, and considerable economy effected in the processes employed. In theory, it should be possible to take the tin stuff, directly from the stamps grate, and allow it to pass over the dressing apparatus—carried onward by the water flowing at different rates, which should be of easy adjustment—until black tin alone remains to be landed in the "burning-house" for the separation of the arsenic or sulphur, and the oxidation of the iron. The removal of the iron and the thorough cleaning of the tin is a process requiring care; but it appears to be a simple one, for which the ingenuity

of our mechanics should devise complete machinery. Every time the tin-stuff is handled, be it by boy or girl, the cost of the "dressing" of the ore is increased. By automatic machinery this might be avoided, and considerable saving secured. All that has been said in reference to the dressing of tin applies equally to copper and lead ores. The difficulty with these, especially with the ores of lead—is in removing from the galena the sulphides of zinc, copper, and the iron pyrites—which are frequently mixed with the sulphide of lead in the ore. Jigging machinery has been introduced, and described, which effects this separation partially; but the specific gravity of the minerals is so nearly alike that some delicate arrangement is still required to render the separations complete.

To return to the question of the depth to which we may penetrate the Earth's crust with a probable expectation of finding metallic minerals in sufficient quantity to pay for their extraction, the answer must continue to be to a certain extent conjectural.

We have shown that it is a fair deduction to assume the existence of a *metalliferous zone*, within which are confined those ores which are of commercial value.

We have endeavoured to make it clear, that between the Permian and the Lower Silurian rocks, there exists a series of strata in which the ores of the useful metals are generally deposited. There are some metalliferous minerals, and many earthy ones, which are discovered both above and below this hypothetical zone. Iron ore is a striking example of this; being found in the most recent as well as in the oldest deposits. This is, without doubt, due to the general diffusion of the oxides of iron in all rocks, and its ready solubility in water charged with carbonic and other acids. By waters percolating through the fissures in the rocky beds, the minerals may be carried to any depth, and deposited in any stratum, irrespective of its geological age. Manganese to a certain extent resembles iron, and consequently we find the ores of that metal near the surface, and at nearly all depths reached by the miner. Zinc ores are found in the iron ores of Northampton and in the older rocks of Central Europe.

The metalliferous zone, which we have ventured to suppose exists, is of such a thickness that no miner will ever penetrate to its lower beds—that is, supposing them to lie undisturbed in their geological order of arrangement. We know, however, that owing to the vast mutations to which the superficial crust of this planet has been subject the order of deposit has been considerably altered, and, therefore, that the lower rocks may be found coming up to the present surface. This, of course, leads to great irregularity, and considerable knowledge is required on the part of the miner to determine when he passes from a metal-bearing rock to one which is not productive of ore. The facts, as we know them, are that our miners have penetrated, in a few cases, to nearly half a mile, and they find the lode which has been traced—in Dolcoath to that depth—is at first a tin lode; the fissure then became rich in copper ore, which gave place to tin in depth, and continues purely stanniferous. The lode, too, is typical of the district, and in many of the mines around Carn Brea conditions exist which fairly lead us to expect that the lodes in depth may prove as rich for tin, as the lode referred to is proving.

At Tresavean mine the lode in Granite continued well defined down to about the 300 fathoms level, then it was almost suddenly lost—that is, the *yellow copper ore*, instead of being confined within defined walls, as a lode, was diffused through the Granite rock itself. Similar conditions have been observed in other mines, although not to the same depths. At both Dolcoath and Tresavean mines, the upper portion of the mineral vein produced tin; then copper ore came in; and, in the first-named mine, tin again occurs below the copper ore. The Granite rocks in which the copper ore and the tin of the mines named occur can scarcely be said to find a place in the metalliferous zone, since they penetrate from great unknown depths, and pass through the upper strata. They and the Elvans are interfering causes, which may, however, be fairly brought within the hypothesis, in favour of which the argument has been supported, by supposing that the varieties of those rocks known as "The Miners' rock" belong to another order than those which are commonly employed for building purposes—one variety being friable, coarse, and fissured; the other being coherent and enduring. By referring to Capt. Charles Thomas's remarks, this will be more clearly understood.

It appears probable that tin, which has been one of the most superficial of the metallic ores, will be found to a considerable depth below the level of the subterranean *exploitation* of existing miners. Copper, on the contrary, would appear to be more limited in its range, and probably will not be found, as an ore, at depths far below those reached, in quantities which will pay for the increased cost of raising it. Lead is in all probability limited to the Limestone rocks and to the Clay-Slates. Mr. Wallace, from his examination of the lead lodes of the North of England, was led to advance an hypothesis that the lead deposits were always found above the present water-shed of the country. Although this is partly true with regard to the Alston Moor district, the hypothesis has not been supported by the conditions of lead lodes in other localities. Still, the inference which appears the most reasonably drawn from the study of the lead lodes of Cornwall, of Wales, and other districts, is that they do not penetrate the Earth's crust to so great a depth as tin does.

It is difficult to answer the question as to the probability of these being unexplored districts which are deserving the attention of mining adventurers. The miners of these islands have been for more than two thousand years employing every natural method for discovering mineral veins, and many supernatural ones have been called in to aid them. Therefore there scarcely remains a piece of ground, in any mineral district, into which they have not pushed their searches. In Cornwall and Devon it has been found that all the productive mines have been found near the junction of the Granite and the Clay-Slate (*Killas*). An examination of the geological maps of those counties will show that by far the largest number of mineral lodes are discovered near the junction of dissimilar rocks, and that as we extend our inquiry away from the lines of junction, the lodes diminish in number, and the value of those disclosed becomes less and less, with an increase of distance. There will be found, however, that there yet remains some few districts, in which such conditions prevail as are supposed to be favourable

to the production of the ores of the metals. It would not be prudent to name any of these, since such indications might lead to expensive searches, which would only end in loss and disappointment. All the conditions under which veins of a productive nature are known to occur have been already described. A careful study of those will prove to be the most reliable guide, for any adventurer, in this always uncertain field. In the present state of our knowledge, experience alone must be our guide in searching for mineral veins, and for determining if the lodes found are sufficiently promising to warrant the expenditure of capital in exploring them. It would be an interesting experiment to obtain, by general subscription, a sum of money sufficient to sink a deep shaft, some few hundred fathoms deeper than any one at present sunk, in a carefully selected district, with a view to the examination of the geological and physical conditions of the underlying rock, and to determine the character of the fissure veins, or other mineral deposits, which may be discovered at these extreme depths.

CHAPTER IV.

IMPROVEMENTS AND ECONOMY IN WORKING BRITISH MINES.

THAT the British mines may be worked, and the ores prepared for the smelter, at less cost than is usually the case at the present time, is beyond all dispute. In every division of the miner's labours there is room for considerable improvement. We have recently seen the advantages derived from the use of the boring-machine, the employment of which is gradually extending. So considerable a space has been devoted to the description of these machines, that nothing remains to be added to the matter already given. The introduction of the new explosive agents has led to much economy in the sinking of shafts and the driving of levels. The advantages of the mechanical borer, and the more powerful explosives, may yet be considerably extended.

Ventilation becomes more important as we carry out the more rapid processes of exploration. It will be seen, from the evidence already given, that very great differences of opinion exist as to the chemical condition of the air after the employment of various kinds of explosive agents. The senses must not always be relied on as giving correct evidence upon this point. The chemical examination of the results of combustion should be alone depended on as a guide. The decomposition of nitro-glycerine, of dynamite, and of explosives belonging to that class, produces gases which are invisible, and extremely insiduous, which cannot fail to be injurious if frequently breathed. The inspiration of the air containing the products of the nitro-glycerine compounds has been often found to produce unpleasant sensations in the head, and in extreme cases, noises in the ears, with, sometimes, bleeding of the nose. Therefore machines for ventilating our metal mines,—of a more perfect form, and more simple in their operation, than those now in use,—should be introduced. The means of ascending from the bottom of our deep mines should be rendered more effective and less laborious than they now are, and the descent of the miners should be facilitated without introducing new elements of danger.

With a view of obtaining the best possible information on the question of working our mines more efficiently, and with greater economy, letters have been addressed to miners of known ability, and of great experience, and to the proprietors of mines who have long been acknowledged as the best authorities. The following replies have been selected, from a considerable number of letters received, as being of considerable interest.

Suggestions for working economically Tin and Copper Mines of Cornwall, by an experienced Miner.—1. The Miners should relieve underground, and generally three cores in twenty-four hours should be adopted.

2. In mines of any considerable extent,—say beyond a depth of 50

fathoms—it would be advisable to send down and draw up the men by means of a small horizontal steam-engine and "gig" running on guide ropes, as at the Minera lead mines in North Wales, where, during the last twenty years, the same apparatus has been employed sending up and down from 300 to 500 men daily. In fact every facility should be given to the men to get to their work quickly, and without suffering fatigue.

3. The disposition of adventurers and mine agents should be to increase rather than to decrease the rate of wages, and thereby to insist upon more work and the production of a still better class of workmen than exists at present.

4. The *tribute system*,—particularly in poor and extensive mines,—ought to be encouraged to the fullest extent, since each individual tributer may be considered as an independent adventurer, exercising his individual judgment, and as having a keen and direct object in discovering ore, and sending to surface not only the orey stuff he may discover, but also free from worthless "*deads*," thereby saving hammering, drawing, and dressing charges. In fact, poor and extensive mines may continue to work for many years on tribute, paying cost and making more or less profit, which could not exist for six months without incurring a heavy loss if worked on *Tut work*.

Materials.—5. The steel should be of the very best quality, and the "points" thoroughly well sharpened and tempered. In fact, so important is this subject that it would be well to offer a premium for—

(*a*) A stove or furnace in which the tools should be heated at the proper temperature, and never overheated or burnt, for sharpening.

(*b*) A tool-sharpening machine.

(*c*) A tempering oven.

At present, one smith will sharpen and temper steel well, another badly. Soft burnt, or badly-tempered borers, will seriously diminish the aggregate depth of hole which can be bored per core—render the general progress of work much slower, and increase the cost of the work itself, throwing a larger increment of the "*dead*" upon the exploratory cost.

6. The object of the miner should be to minimise the boring labour by substituting explosives, so far as it may be economical to do so. Small holes should be bored at the bottom so as to be not of greater diameter than the dynamite cartridge used.

A hole two inches diameter, bored to required depth, will take about four times the length of time and power to bore, as a hole one inch diameter to an equal depth.

Railways.—7. The "ways" should be well laid and maintained, the waggon wheels properly greased and set upon the axles, and the wheels for any considerable traffic provided with oil boxes.

Pumpwork.—8. The pump cisterns should be kept clean, the holes in the windbores open, the plungers well attended to, the buckets and clacks properly maintained, and the rubbing pieces frequently smeared with grease.

Engine.—9. A system of indicating the engines once in two or three months might be advantageously adopted, and the old rivalry between engineers, by reporting the duties performed by the engines, should be restored if possible.

Pumping. As the mines must necessarily get deeper, and greater comparative cost incurred in pumping, every care and consideration should be given to the engine with the view of realising a greater unit of power, from a given weight of coal. With this object the coal should be of the highest calorific value.

It should be fresh and dry, free from shale or dust.

It should be properly distributed on the fire-grate.

The boilers should, as far as possible, be fed with pure and non-corrosive water.

The boilers and flues should be cleansed at stated intervals.

The boiler flues should throw the heat on the boiler shell, and not in any way open to allow the heat to "run" or flow through into the rubble work or masonry.

The boilers should be efficiently covered, to prevent the passage of heat from the upper part of the shell.

The feed-water should be taken from the condenser as hot as possible.

The steam pipe should be effectually covered.

The main pistons should be packed when necessary.

The valves ground to the seating when required.

A vacuum gauge fixed between exhaust valve and condenser.

The late Mr. Charles Fox, of Falmouth, who all his life through exhibited the utmost interest in improving the condition of the Cornish miner, and to whom we are indebted for the introduction of labour-saving machines into the Cornish mines, in reply to some inquiries said:—

"The great difficulty *is* to get the attention of minds so focussed, and thus practically brought to bear, on mining arrangements, as to promote reform." With this introduction he handed the following *Mining Memoranda*:—

"Leases should include a larger extent of ground, and be less diffuse. If lessees were allowed, on building dwelling-houses for agents or miners thereon, to hold them for a term of years, as well as cultivated plots, encouragement would be given thus to promote the welfare of the miners and to keep them near their work.

"Mines are overcome by water (or in danger of being so) when adjoining mines are in different stages of progress or prosperity. These should be rendered more or less mutually dependent—the Setons for instance. Such mines as Dolcoath and Cook's Kitchen should have been one concern. With more ground a larger engine might be erected, and a relatively larger engine-shaft be sunk. Now the cost is greatly increased from separate establishments of 'plant,' &c. The fixed machinery, dressing apparatus, carpenters' and smith's shops, counting-houses, &c., are multiplied, and in many, if not in a majority of cases, ere long abandoned.

"Central chemical or metallurgical works (not in a mine partnership), for dealing with the mixed ores of various mines, could render advice on the advantageous treatment of them where adventurers in individual mines would not incur the cost of experimental works. Our mining students might then benefit by a practical experience in such a treatment of our ores as is now carried on in Newcastle, and other Mining Schools.

"The price of copper admits (1872) of a fair profit, if discoveries of new lodes of moderate produce were made. The high price of tin for a few years checked the opening of copper mines. There are still large fields only partially explored about St. Just, Marazion, Godolphin, the North Coast, St. Blazey, Bodmin, Liskeard, Hingston Down, &c.

"Where the ground does not admit of a deep adit being rapidly driven by a boring-machine, traversing various strata and intersecting all lodes, the erection of an engine on an abandoned shaft, which might pump the water, draw the stuff from one end, and work a boring-machine, might enable adventurers at a small outlay to 'anatomise,' as it were, the very viscera of the region, by penetrating them at the rate of 300 to 500 yards in a year.

"It is the fast pace that cripples or kills the horse, the slow that knocks the *ball* (*Mine*).

"You harpoon the whale, and he is yours; you might wound him with knives from head to tail, and get a blow from his tail, and your lot be worse than in the Vice-Warden's Court.

"If dispatch in opening copper mines be needed, how much more in tin lodes (generally in harder ground or of a harder nature), and having to contend against a reduction of price of more than 50 per cent. Pitches of low produce, where the tin-stuff may be broken for 3s. or 4s. per ton, must be passed by, as it will not under ordinary circumstances pay all the charges. If the leading captains would note the distance which often separates a good piece of tin ground from another,—calculate the time required to cut a side lode at a much deeper level than that at which it was promising nearer the surface,—or the time needed to sink the sump 10 fathoms to get more *backs*, they would add the weight of their testimony to the vital importance of assisting manual labour in driving levels and sinking shafts by machinery, at once purifying the ends and preserving the heart and lungs from excessive exertions under damaging circumstances.

"Registers should be kept in each mine of all the men working underground, date of birth, their ages on first working below the surface, and how often under medical care. There should also be a medical register kept in each mine.

"An accurate comparison of the relative advantages, or disadvantages, of ordinary stamps, as compared with pneumatic or spring stamps, is greatly needed, also of the cost of working locomotive stamps, such as might return accumulations of *halvans*, or tin-stuff raised from shallow *backs*. There is reason to doubt if the breaking machine is sufficiently used, enabling a cleaner picking of coarse work, so as to diminish cost of stamping, buddling, &c. Dingey's pulveriser may be most useful. Should not a competent captain be appointed to compare different modes of dressing ores,—especially those of tin, or of tin mingled with blende or copper pyrites,—whether in the many modes of buddling, Froude's or Taylor's separators? The rotatory calciner has a strong claim over the costly ovens, demanding much labour and care.

"It will not do for Lords to forbid selling tin in the stone. They may thus stifle a mine at its birth, before adventurers have any certain data to warrant the erection of machinery.

"If the tin-stuff be carefully spalled, and a selection be made of its better work, the carriage to the buyer's stamp at a moderate distance would be expedient, and encourage numerous trials. There are some mines in which there are ample spaces for lodging attle instead of hauling it to grass.

"The steady price of lead should encourage a much more diligent search for lead lodes than is now the case in Cornwall; they will be found most numerous away from the copper and tin lodes.

"Alas, how much ought to be done for the further education of our working miners to make them skilful labourers, either in mining or in kindred pursuits, such as smelting, or being useful in various chemical processes. To engine and pit men,—in some of the responsible positions in the construction of railroads, ever stretching more and more over the globe,—some knowledge of hydrostatics is ever found useful, both in mining and in the various public works, in which an intelligent miner will be always valuable, both at home and abroad. But our present funds are not sufficient to teach the very elements of some of those branches of learning,* which they are eager to cultivate if properly aided. Plane geometry should be sedulously studied; a practical knowledge of electro-magnetism opens a fair field for employment for young men. R. W. Fox has shown that it reveals hidden secrets underground—the true divining-rod. Not later than 1838 he discovered that the Earth completes the circuit, otherwise two cables would be needed between two continents; and doubtless the electrometer might show if two bunches of ore, at some distance from each other, had a metalliferous connection and were separated by barren rock.†

"I have often imagined that the subject of alloys offers an illimitable field for research: that practically we know but little of the extent of the uses of tin if alloyed with different metals in various proportions."

A *most experienced mine agent*, who, although an imperfectly educated man, had, by his powers of observation and the application of his acquired knowledge to many useful ends, been a valuable adviser, furnished shortly before his death the following notes in answer to sundry inquiries made:—

"You inquire respecting the cost of raising and dressing ores of tin and copper at per ton. This is a very difficult question to answer, as scarcely two mines are alike. It seldom happens that the different levels in driving or stoping are similar. 1st.—In some mines, the rock is very hard to break; in others, much more decomposed;—the cleavage is often much better in one mine than in another. Sometimes, in consequence of the ventilation being bad, the price for breaking varies, so that it is charged from £2 to £30, or at even more per fathom; and as it is with levels driving, so with stopes. The distance of the workings from the shaft, for the removal of the stuff, also, makes a difference, as we have to pay more for wheeling or traming.

"The average price per ton in our mine, for breaking and bringing to surface (as the contractor is supposed to pay all cost) is about 7s. per ton, but even then the averages of two months are not alike; but in some other mines it would be only 2s. Again, the tin-stuff varies as to quality; one

* Mr. Charles Fox refers to the expenses of teaching science in the classes of the Miners' Association.
† See Mr. Robert Were Fox's Experiments, pages 222 and 389.

ton broken in one place at 9s. per ton produces only 28 lbs. of black tin to the ton of stuff; at another place, at the same price (9s. per ton), it produces 12 cwts. to the ton. So that as it regards price and produce we can say but little as a guide for other miners.

"As to the dressing of tin ore, this also differs considerably in its cost. In the first place, the stuff is drawn to surface small, because of its being more decomposed, or with a more favourable cleavage, so that it requires little or no '*spalling*'; in the other case we have to pay 6d. per ton for *spalling*. The distance to carry the stuff after being spalled to the stamps makes a difference also.

"Again, tin-stuffs have frequently a quantity of pyrites, or sometimes wolfram, or other foreign matter mixed with it, in greater or less quantities, so that some tin-stuffs pass through the dressing process with one-half the trouble, and consequently less cost. Again, the more pyrites in the ore the more coal is required to calcine it.

"Much also depends on whether you apply water or steam power to drive your machinery. This may apply also to the breaking, and dressing, of copper or tin, only the cost is not near so great for the former as for the latter. Tin-dressing with us, in consequence of so much foreign matter, costs us 6s. per ton of stuff, while tin at other mines may be dressed for 2s. per ton.

"To make a mine pay in these times the greatest attention must be paid to the machinery. I have known parties carry their economy too far; through the want of a little attention to the lapping of the joints underground, the air enters, and the engine performs only half duty, and frequently in some shafts the friction is unduly great around the main rods, which means cost of coal. Our Cornish engines should be made to do better duty also, but the managing agents have other property to think about, and the working engineers are not allowed to think in many places, so that there is a larger quantity of coals consumed than ought to be. In our mine I have long contested this point, and it is only recently that I have been improving slowly our steam stamps. We are now saving about 20 tons of coal per month by properly adjusting the gear, without any new arrangement.

"At our drawing, or winding, engine I long advocated a better piston and expansion gear; the engineers said, no good would be effected, but I have had it done, and we save now at that engine about 20 tons of coal per month. Great attention to the keeping of machinery in repair well pays for the outlay."

The question is frequently asked, Is British mining a remunerative pursuit? Various replies might doubtless be given in accordance with any particular set of views and opinions held on the subject; but mines promoted by mere speculation can scarcely be expected to become profitable, inasmuch as they are too frequently grounded upon a misrepresentation of facts, while the capital connected with them is often largely diverted to the pockets of individuals whose main purpose is immediate gain. Further, the management or conduct of affairs is often leavened with ignorance and incompetency; the acquisition of personal gain, at the cost of unsuspecting shareholders, being unfortunately sometimes the rule of action.

If, however, the matter be treated as an industry, in which care in selecting the properties, and ability, skill, and economy in working them, are to be exercised, in such case it is beyond doubt that mining may, on the whole, be rendered a profitable pursuit.

The following particulars are the actual results of working eighty-eight tin, copper, and lead mines in the United Kingdom, during a period of thirty-seven years, the technical operations having been under a general manager, distinguished for the purity of his character, his excellent businesslike abilities, and singleness of purpose:—

Year.	No. of Mines at work in Year.	No. of Mines closed in Year.	Total Amount of Capital invested.			Annual Amount of Profits divided.			Annual Amount of Capital invested.			Amount of Capital returned from Mines abandoned or sold.		
			£	s.	d.	£	s.	d.	£	s.	d.		s.	d.
1819	6		6,649	6	5	7,680	0	0	19,219	12	5			
1820	6		25,868	18	10	7,862	18	5	41,988	14	10			
1821	6		67,857	13	8	18,680	0	0	20,427	2	4			
1822	8		88,284	16	0	41,320	0	0	12,588	5	2			
1823	14		100,873	1	2	50,304	0	0	104,383	6	2			
1824	19		205,256	7	4	49,440	0	0	163,439	9	8			
1825	24		368,695	17		87,398	4	6	145,677	3	2			
1826	24		514,373			54,208	3	2	30,430	18	2	4,000	0	0
1827	24		540,803			73,929	1	3	6,255	7	4	10,960	0	0
1828	24		536,099			70,889	6	9	6,127	7	10	7,500	0	0
1829	24		534,736			40,720	10	8	84	4	11	7,035	8	9
1830	23		507,038			27,471	9	8	21	18	8	2,060	0	0
1831	18		484,334			36,399	13	3	5,222	8	6	2,340	15	0
1832	17		478,486		8	34,082	12	7	275	19	8	1,680	0	0
1833	18		478,152	8	10	43,025	10	0	8,820	0	0	3,340	0	0
1834	16		401,829	0	1	56,860	5	10	7,420	0	0	560	0	0
1835	17		408,387	0		37,410	9	3	5,195	0	0	1,105	0	0
1836	24		373,582			69,749	0	0	11,984	0	0			
1837	26		385,566			38,832	0	0	12,970	0	0	700	0	0
1838	27		397,836			32,250	6	6	12,420	0	0	8,219	0	0
1839	27		381,606			82,914	7	6	17,115	0	0	6,220	12	6
1840	26		376,054	0	0	41,980	0	0	13,828	16	0	66,804	13	0
1841	25		314,214	0	0	24,740	0	0	15,416	0	0	2,086	8	6
1842	24		298,599	13	7	17,144	15	0	24,709	0	7	1,175	0	0
1843	24		303,424	1	1	13,340	0	0	11,694	10	0	265	1	4
1844	23		280,028	11	1	21,500	0	0	8,434	0	0	2,394	8	0
1845	24		280,563	11	1	30,601	12	0	3,416	0	0	1,677	6	10
1846	21		278,337	7	1	33,596	15	5	5,442	0	0	5,378	19	3
1847	22		269,693	12	6	23,800	0	0	12,688	0	0	3,766	13	8
1848	22		261,381	12	6	13,189	12	4	20,982	3	5	1,672	10	4
1849	21		224,376	14	10	19,147	0	2	29,784	0	0	792	8	10
1850	29		241,603	2	7	22,454	8	11	35,538	0	0	408	1	1
1851	32		274,995	11	6	21,321	0	0	35,134	0	0	14,170	6	0
1852	33		286,913	5	6	26,702	3	4	44,337	0	0	4,357	7	6
1853	35		307,082	5	6	22,425	16	8	46,462	10	0	3,193	0	0
1854	36		359,370	5	6	26,294	8	11	34,082	10	0	5,850	4	9
1855	36		385,058	15	6	24,601	3	4	46,469	1	6	2,681	10	6
		53				1,344,266	15	5	1,020,483	10	4	173,364	15	10

	£	s.	d.
The total amount of capital invested in eighty-eight mines was .	832,234	4	5
Less capital raised on fifty-three mines stopped and accounts closed .	447,275	8	11
Capital invested in thirty-five mines	384,958	15	

II.

	£	s.	d.
Total amount of profit realised and divided on eighty-eight mines to years 1855 inclusive	1,344,266	15	5
Amount of capital returned from mines abandoned or sold . .	173,364	15	10
Total amount returned on £832,234 (capital invested)	1,517,631	11	3

III.	£	s.	d.
Total amount of profit divided on fifty-three mines abandoned or sold	819,125	15	2
Amount of capital returned from fifty-three mines abandoned or sold	173,364	15	10
	992,490	11	0
Capital invested in ditto	447,275	8	1
Net profit over and above the return of the capital sum	545,215	2	11

It will thus appear that the return of money on the total capital invested, £832,234, exceeded the latter sum by (£1,517,631 11s. 3d.—£832,234) £685,397 11s. 3d., and that the profit on fifty-three mines at work, after deducting the capital, £447,275 8s. 1d., was £545,215 2s. 11d. From the table itself the percentage of profit on the capital for any given year may be ascertained. Thus in 1823 the profit accruing on fourteen mines then at work was (£100,873 1s. [illegible]d. : £50,304 :: 100) $49\frac{8}{10}$ per cent., while on fifty-five mines in 1855 it only amounted to (£385,058 15s. 6d. : £24,001 3s. 4d. :: 100) $6\frac{3}{10}$ per cent.

A considerable amount of thought has been for many years devoted to the condition of our mines and our miners. Reflection on the present state of things renders it exceedingly difficult to suggest any reasonable means by which we may hope to improve the future of British mining.

It appears certain, as is clearly shown by the above returns, that mining—entered on by the assistance of judgment matured by experience and honestly directed—is of a far less speculative character than it is generally conceived to be. After carefully considering all that has been advanced in this volume, it will be, as we think, clear that there are certain rules—we must not even yet call them laws—by which an adviser may guide his clients, either to venture on spending money in search of mineral veins, in a given district, or to leave untouched the uncertain ground.

In 1856 the late Mr. John Taylor, who was regarded by all as a good authority, stated before a committee of the House of Commons "that there were no greater facilities for ascertaining the productive character of a mine now than formerly. The difference was simply in improved machinery. Our knowledge was not greater than that of our forefathers." This is the proper place, after this record of his remarks, to give some notice of the influence exerted on British mining by Mr. Taylor. At first it was thought advisable to relegate to a note all that it was necessary to write with regard to the influence of this individual mind on a great national industry. Careful reflection has established the advantages to be derived from giving in the text itself a prominent position to the works of a man who, by devoting the powers of a well-trained mind to the improvement of a national industry, relieved it from the pressure of many evils, and established it upon a firmer basis than had previously been secured for it.

"We cannot here go into the detail of the improvements of various kinds which he (Mr. Taylor) devised and effected for the advancement of the art of mining, the profit of the adventurers or the physical and moral well-being of the men; suffice it to say, that in all respects his administration was eminently successful, and that he gradually took his station at the head of his profession." *

* Quoted from a Memoir by one of Mr. John Taylor's relatives.

Mr. Taylor was educated as a land surveyor. At an early age he was selected, by some of the shareholders in Wheal Friendship mine, near Tavistock, to undertake the management of that important concern. He introduced numerous reforms in every department. He was fully persuaded of the superior skill and industry of the English miners, but he did not attribute their superiority to the absence of scientific training.

"If," writes Mr. Taylor,* "what has become the theme of praise in other parts of Europe be not applicable to England, it must be either because our mines do not require intelligence and skill for their management, or that our miners are not likely to have their intelligence and skill advanced by the most obvious means of doing so.

"As to the first, it is well known that one effect of late efforts in mining in England has been to deepen the mines with a rapidity totally unprecedented [*this was written in* 1829], to consolidate small concerns with larger ones, to explore more perfectly the ground in all directions, to adopt means that might render labour productive of profit, to stimulate the labourer by combining his interests with that of his employer, to watch every symptom with care, and to employ every device that ingenuity could suggest to overcome difficulties. It must, then, obviously follow that there is a greater demand for skill in the conduct of these affairs as the mines are increasing in depth and extent. Numerous expedients to counterbalance these difficulties are required; and as the expense increases, compensation must be looked for in the aids that science may afford."

Mr. Taylor then points out the need for a School of Mines, the details of which he arranges under the following heads:—

1. The things most proper to be taught.
2. The class of persons who may be expected to be scholars.
3. The Professors.
4. The situation of a School of Mines.
5. The probable expense of the Institution.
6. The means of providing the necessary funds.
7. The Government or Direction.

This plan met with no encouragement at the time, but it cleared the way for the School of Mines subsequently established by the influence and energy of Sir Henry de la Beche. Mr. Taylor greatly admired the qualities which he discovered in the miners of Cornwall and Devonshire. "If I were to say much of what I think of the talents they commonly possess, and of the excellent use they make of the means of instruction, slight as they are, which are thrown in their way, it might appear that I meant to flatter men with whom I am much associated, and to whom I am so much indebted. Miners in general are a superior class of men, and, in the deep mines particularly, the constant exercise of judgment and thought which is necessary produces a proportionate degree of intelligence."

Mr. Taylor had the management of the mines near Tavistock from 1799 to 1812. He then became the manager of the United and Consolidated mines in Gwennap, in Cornwall. In 1820 he was requested by the Duke of Devonshire to superintend the workings on his Grace's mineral property in

* "Records of Mining" ("Prospectus for a School of Mines in Cornwall"), published in 1829.

Staffordshire, in Yorkshire, and in Ireland. In 1822 he undertook the direction of Lord Grosvenor's mines in Wales, and in 1823 the Commissioners of Greenwich Hospital placed their important mines on Alston Moor in his hands. In addition to those mines in the United Kingdom, Mr. Taylor was consulted in the management of numerous Foreign mines, and he became the engineer of several of them.

Mr. Taylor was one of the earliest members of the Geological Society. In 1816 he was appointed its treasurer, which office he retained until 1844. In 1825 he was elected a Fellow of the Royal Society. He was one of the earliest and most active members of the British Association for the Advancement of Science, the first council meeting of that body being held in his house in Bedford Row on the 20th of June, 1832. He was a trustee and treasurer of the British Association until 1861, and was also treasurer for many years of the London University College. One of the most advanced philosophers of the age wrote of this excellent man: "The high estimation in which Mr. Taylor was held by men of science you will find in every word which they utter concerning him. I never knew a man so entirely loved and admired, so firm in his judgments, and yet so mild. He seemed more than a philosopher—a wise and good man." *

The influence exerted by Mr. Taylor on mining generally was most remarkable, and as it regards Cornish mining was of especial importance. Every branch of mining was improved, new machinery was introduced, and the condition of the steam pumping-engines was during his reign so greatly improved that the Cornish engine became a pattern to the civilised world. Mr. Taylor's management distinguishes and marks an epoch in British mining, which is, at the present time, in an analogous position to that which marked it at the beginning of the century. By honesty of purpose, by well-directed industry, and by devotion to the business of subterranean exploration, he restored mining to a healthful and profitate state. As then an important industry was saved from ruin by the energy of one mind, so now the sad state of depression—notwithstanding the competition of Foreign mines with our own—which reigns in all our mineral industries, might be relieved by the zealous efforts of a trained man, who would keep himself free from the seductions of speculative adventurers.

The difference observable between the "Then and Now" of mining cannot be more satisfactorily shown than by the following letter from a gentleman deceased, who held the highest position as a practical metallurgist in the county of Cornwall, and whose family had for several generations been the leading spirits in Cornish mining:—

"I am much obliged for your letter of the 12th inst., and quite agree with you in principle on the present state of Cornish mines, and on their not having improved in conformity with advances for conducting many of our manufactures in this country. In going into business we have several

* In the "Transactions of the Geological Society of London" we find four papers on Mines, Mining, and Metallurgy; in the "Philosophical Magazine" ten memoirs; and in the "British Association Reports" five important communications, by Mr. John Taylor.

important points to consider, viz. first capital, then partners, and next, th most important of all, *management*. I think these three comprise th greater portion of the question of Cornish mining being on its wane. I hav a very small interest in only one or two Cornish mines, and if I say anythin deteriorating I do so with the hope that it may lead others to remedies whicl may be for the county's benefit generally. We have *plenty of minera produce left in Cornwall*, but to work it profitably we must have *efficien managers* if we intend to retain adventurers' capital, for without their con fidence we cannot expect to do so.

"As to machinery, this has been much neglected, as mentioned by Mr Richard Taylor last week at the Polytechnic meeting. One of the grea losses to our county I consider the system now adopted of stoping ground instead of working on tribute. The new plan opens a door to the graves abuses, and ought to be driven out as much as possible. The old Cornisl tributer did more work and benefit for his employers, than I ever experiencec in any system of employment. The tribute workman is a partner, and largel interested in his undertaking. The question of *efficiency* of agents is a ver serious one, and ought to be regulated by the manager, aided by a committee in that important matter, as well as all others. In writing Mr. G. L. Bassett recently about the boring-machine, I have endeavoured to convey the same views as expressed in the foregoing, about Cornish mine management and the dues surrender. The latter I should treat as a business question, and expect the underground, and the capital, account to be placed in a satisfactory state. No loans at bankers or uncharged cost."

This was followed—in answer to an acknowledgment of the previous letter—by the following reply:—

"I am much obliged for your letter of the 23rd and for your kindly writing me so fully on the state of our unfortunate mining affairs, and though I, to a great extent, reciprocated your views, yet the question is so serious, lengthy, and weighty, that with my other engagements I cannot venture to go into the question to try to assist you in detail. I have for a long time tried to form some new plan for the advancement of the Miners' Association, particularly to produce a better class of men for mine managers." This leads to a few words on Mining Schools—their origin in this country, and the advantages they offer.

In October, 1838, Sir Charles Lemon, Bart., M.P., issued a circular to mine agents and others throughout the county. After insisting on the necessity for scientific instruction, he made the following liberal offer:—

"With a view to ascertain how far there is a real demand for such (scientific) instruction, I will take on myself the expense and responsibility of an experiment for two years. If I should find on considering the details that my plan offers a reasonable prospect of success, and if at the end of two years the county should take up the subject and carry it forward till my death, I will endow the institution in such a way as shall afford a reasonable hope of its permanence."

Subsequently Sir Charles Lemon offered—

1. A sufficient site for building a college.
2. £500 contribution to the building fund.

3. "I will, as far as I am able, provide that a sum of not less than £10,000 shall, at my death, be placed in the hands of trustees for the use of the college, and should this sum prove insufficient for the purpose contemplated, I am willing to make it £20,000."

An experimental school was organised at Truro, and three teachers were appointed in 1839. It was not a success. In 1840, the school was again opened at Truro: a few pupils only attended. Sir Charles Lemon now renewed his offer, but owing to sectarian views it was not accepted. In 1853, twelve years having elapsed, another attempt was made—in this instance by the Royal Institution of Cornwall; and in 1859 it was abandoned, the "number of pupils being very small."

In the interval, Sir Charles Lemon proposed to the author of this volume,—who then filled the office of Secretary to the Royal Cornwall Polytechnic Society—to endeavour to establish a class of young miners in a school conducted by Mr. John Phillips, at Tuckingmill, near Camborne, the very centre of extensive tin and copper mines.

The expense attending this experiment—of taking the school to the miner, instead of compelling the miner to go a considerable distance to the school,—to be continued for twelve months, was equally shared by Sir Charles Lemon and Lady Bassett. This proved a complete success. In 1858 the author addressed a letter to Mr. R. W. Fox, which was read and discussed at the annual meeting of the Royal Cornwall Polytechnic Society, advocating the organization of a Society which should convey to the miner a knowledge in the practical application of science, and receive from the miner the advantages of his experience. From this letter the following quotation is made:—

"'One and all' is the motto of the county, and by co-operation everything is to be achieved. My desire is to show that by a proper union of the mining interest of Cornwall, they may achieve for themselves the utmost benefit of improved knowledge, they may collect and preserve the results of their own careful observations, and they may benefit the commonwealth of science by furnishing those facts by which alone the philosopher can ever truly interpret the phenomena of nature.

"The kind of education which the Cornish miner receives naturally makes him a careful observer, and it is only required that some system should be introduced to render his observations of the highest value, and reject the worthless. Habits of close observation are established, the young man goes underground, and, emulous of being a successful 'tributer,' he soon learns to note peculiarities in the rock upon which he pursues his search for ore. Thus the education of the miner is a continued lesson of observation. . . . .

"The miner can give knowledge while he receives instruction, he can communicate important facts, the result of his observation, whilst in return he is receiving that training and that additional information which would be indeed 'a light to his path.'

"On the 26th of October, 1859, a public meeting in connection with Mr. Hunt's proposal was held in the Town Hall, Camborne. The chair was taken by Mr. John St. Aubyn, and the Miners' Association of Cornwall

and Devon, the fourth and most durable of the mining schools, was founded."*

The objects of the Association were stated as follows:—

1. To obtain the record of observations by practical men.

2. To promote scientific knowledge among the miners.

3. To consider the means of relieving the miner from the toil of climbing from great depths.

4. To introduce approved processes employed in other parts of the world.

5. To obtain plans for establishing improved ventilation in our mines.

6. To determine the mechanical value of blasting powders, and to make known improved methods of blasting.

7. To promote the application of machinery for excavating.

8. To aid the young miner by classes in the neighbourhood of the mines, with elementary instruction in the facts and principles of mechanics, geology, mineralogy, chemistry, hydrostatics, pneumatics, and other sciences connected with mining.

We conclude our notice of this effort to secure for the future of mining a system of technical education which shall be adapted to the wants of the miner, and which shall tend to improve in every way the operations of mining, in the words of Mr. Charles Fox, who was in 1861 elected president of the Miners' Association for two years:—

"The Miners' Association of Cornwall and Devonshire shall devote itself to the encouragement and advancement of mining and mine engineering; promote the exchange of information and ideas; secure the record of the results of experience and observation; devise plans for the education of the practical miner in the branches of science which bear immediately on mining; establish local collections which shall illustrate the geology, mineralogy, and physical phenomena of each district; and by all available methods aim at the improvement of the great mining interests of England."

In 1862 the author brought before the Society of Arts the subject of the improvement of the miner's education in the following words, which are equally applicable now as then:—

"When the powers of the mind have been directed to any peculiar set of natural phenomena for a prolonged period, we usually discover in hypotheses advanced, and in theories more or less supported by facts, attempts to explain the causes which have been active in producing the effects observed. There is a curious absence of this in relation to mining. Beyond some very undefined notions that fire played an important part in the formation of minerals, or that mineral veins have some analogy to the veins in the animal body, or the branches of a tree, no hypotheses have been hazarded by miners proper. A few men, educated in the Schools of the Continent, and two or three Professors of science in this country, have, it is true, promulgated their opinions, but until Werner published his theory, they advanced but little beyond the creations of fancy. It will not be without interest to examine the causes of this.

"The miner has ever been a distinguishable man amongst the hosts of his brother-men. Working in solitude in the dark recesses of the rocks, he has

* "Remarks on the Successive Mining Schools of Cornwall." By J. H. Collins, F.G.S.

become thoughtful, with only the dreams of ignorance on which to employ his thoughts. Hence he has peopled the subterranean world with '*Kobals*;' and even the smothered sounds of waters dropping in some unopened cave have become to him the realization of the '*knockers*'—unkind gnomes, who mock him in his toils, and who as frequently lead him from, as guide him to, the mineral mass on which they are supposed to labour. Habituated to danger, the miner becomes careless of death, and his life is a constant declaration of his belief in fatality. Superstition finds her fitting home in the dark places of the Earth, and reigns supreme in the dark mind of an untaught man. Therefore the dominant Powers to the miner have been the creations born of ignorance and night. Signs and tokens, lucky and unlucky days, ill-wishes, evil-eyes, witchcraft and charms, were the rulers of his life.

"Although the influences of ordinary school-education have penetrated to the most remote mining districts, and produced the usual humanising effects, yet the miner retains many of the peculiarities which belonged to his forefathers. Whether we examine the miners of Alston Moor, of the dales of Yorkshire, of the hills of North Wales, or of Cardiganshire, the scattered workers of the mines of Shropshire, or the large mining population of Cornwall, we shall discover the same general peculiarities.

"As a body, miners may be regarded as a religious class, but theirs is a religion of the heart, not of the head. They are powerfully swayed by their feelings, to the repression of the influences of reason. Hence the tendency to those impulsive manifestations of a religious conviction which are known as 'Revivals.' Thoughtful we have said they are, but their thoughts flow slowly, and they have ever a tendency to dwell on the darker shades of life; while it is with extreme difficulty that they can be brought to communicate their thoughts to others. Miners are rarely frivolous, even *above* ground; they are especially serious *below*. The youngest men will express their dislike of idle conversation or of joking in the mine, while whistling is strictly forbidden. In the sports and pastimes of a mining village there is something peculiarly sober; and the celebration of the annual feast, with its attendant fair, has something of a sombre character about it, in comparison with agricultural revels.

"A sanguine temperament may be said to distinguish a miner. He is for ever hoping that stores of mineral wealth are a little in advance of his labour. Therefore, although in relation to the ordinary affairs of life he is trustworthy, showing a real love for the truth, he is curiously carried away from it when describing the state of a mine, and he expresses his hopes rather than records his knowledge. The exaggerations exhibited in some reports on mines are often of an amusing character, running, indeed, into poetical rhapsodies. Many an unfortunate adventurer has, however, to date his ruin from the day when he gave credence to the hyperbole indulged in.

"From their very childhood miners are trained to observe. As boys they are employed to separate the valuable ore from the useless stones, with which it is mixed, and this is often a delicate operation. In their labours underground everything depends upon their careful observations, especially in those mines where the system of 'Tribute pitches' is adopted; the miner (*Tributer*, as this class is called) receiving an agreed share of the profit

derived from the sale of the ores, which he breaks out of the lode. Yet their *powers* of observation are of a very limited order. Their experience is made up of a knowledge of peculiarities existing within a confined area. So long as these repeat themselves the miner's deductions are correct; but vary the phenomena ever so slightly, and he is at once at fault. This is continually occurring. Within the circle of their labours a few men will probably arrive at a tolerably exact knowledge of the conditions existing, and this knowledge gives them a pre-eminence amongst their fellow-miners as advisers. But remove one of these men from his own locality, he is rarely able to group the new phenomena presented to his view; he feels he is ignorant, though he is rarely so boldly honest as to proclaim it; and he commits himself to statements which are only vague guesses, happy, indeed, if any one of them proves correct.

"It is interesting to note the unmistakable Celtic manners of the south and west of England, and then those which have a more directly Teutonic origin, of the northern districts. There are differences in the habits of life of the man, but the idiosyncrasies of the miner are the same. This may be due in part to the intermixture which has taken place between the mining races. The German miners who came to England when Elizabeth was queen, settled, some in Cumberland and some in Cornwall. Edward the Black Prince is said to have taken many hundreds of the lead miners of the northern counties to work the rich silver-lead mines of North Devon, and the Cornish miners are allowed the merit of having introduced improved machinery into the mines of Durham and Northumberland. Beyond the similarities which may be traced to this interchange, there are others which clearly belong to the business of mining, and which are probably as old as the days when Job said, 'Surely there is a vein for the silver, and a place for the gold, where they find it. Iron is taken out of the Earth, and brass is molten out of the stone.'

"The psychological influences of subterranean toil form a strange but interesting subject of study. These and the effects of that continued uncertainty, as to the reward which labours of the severest kind are to receive, are distinguishingly marked on every miner. In occult powers they are believers; and when, about a century since, the 'Divining Rod' (*Dowsing Rod*) was introduced into Cornwall—as a means for finding mineral lodes, it was eagerly seized upon, and, to the present day, several families are supposed to possess remarkable powers as diviners, or, as they are commonly called, '*dowsers*.' The most elementary laws of science are still a book sealed to the large majority of miners, and while they are, of all men, themselves the most theoretical, they always meet any attempt to explain phenomena upon the evidences of inductive research, by pronouncing the explanation to be a 'theory,' which is of no value to a 'practical.'"

The Royal School of Mines, which originated with Sir Henry de la Beche, and which with the Museum of Practical Geology was inaugurated on the 14th May, 1851, when the establishment was opened by his Royal Highness the Prince Consort, was an effort to extend the advantages of scientific instruction to all the miners of the United Kingdom. The words of his Royal Highness, in reply to the address presented to him, deserve a

permanent record :—"It is impossible to estimate too highly the advantages to be derived from an institution like this, intended to direct the researches of science, and to apply their results to the development of the immense *mineral riches granted by the bounty of Providence to our isles and their numerous colonial dependencies.*"

The establishment of the Mining Record Office in 1840 has already been mentioned. It is again referred to for the purpose of drawing attention to the fact that in 1883 it was virtually abolished. It is true that the plans of the *abandoned metal mines* collected have been removed to the Home Office, to be placed and preserved with the plans and sections, which by the "Mines Regulation Acts for 1872" are sent to that Department. But all the Plans and Sections of such mines as are now in existence remain at the Museum of Practical Geology, their future destination being uncertain.

The following remarks by one of the best-educated and most practical of our mining engineers are directly to the point, at the present time:—

"Among other causes which have retarded the progress of improvement in subterranean operations, the speculative and uncertain nature of mining is one of the principal.

"But mining, though certainly speculative, is not entirely the work of chance. In it, as in all other business, he who classifies his accounts and can at any time readily ascertain the exact sources of expenditure and income—who derives experience from the constant accumulation of facts—possesses very superior advantages over those who have no such data. *The well-founded calculations of the one are, in the ordinary course of affairs, much more likely to be attended with success, than the vague and unsatisfactory speculations of the other.*

"A reliance on *chance* instead of science—as the presiding genius of mining adventure—must, sooner or later, affect its own existence, by demonstrating that the instances of good fortune bear a very small proportion of the numerous undertakings which end in disappointment, and create a highly injurious prejudice against mining speculations.

"The prevailing idea of the uncertainty of mining adventure, and a consequent disregard of method in conducting mines, are especially detrimental to the interests of all concerned. The *prospects* of mining cannot indeed be reduced to certainty, but it is exceedingly desirable that all the details of conducting it should be so. . . . . *Whatever tends to increase a knowledge of mining undoubtedly contributes to its permanent interests*, and if the present (1883) depression of the markets continue, if prices will not rise to meet the present and increasing expenditure of mines, *there is the greater necessity for the adoption of every means to promote future economy and to prevent future waste.*"

CHAPTER V.

GENERAL SUMMARY AND CONCLUSION.

WITH the concluding words of the last chapter this work might have been reasonably brought to a close.

It appears, however, that some advantage may arise from an attempt to summarise the facts which have deen collected, and to draw, what, it is hoped may prove, legitimate inferences from them. The records of the past have been examined with care, for the purpose of ascertaining, if it were possible to draw any conclusions from them, as to the extent to which the exhaustion of the mineral wealth of the United Kingdom has been carried. Out of this arises the following important considerations as to the future prospects of the great national industry of Metalliferous Mining.

(*a.*) During the long period of which we have any account of the mining operations carried forward in these islands, there has been an enormous quantity of the useful metallic minerals obtained from the rocks in which they were—in remote geological time—deposited.

(*b.*) Notwithstanding this, it has been proved that the exhaustion of our mineral wealth is now going onward at a rapidly increasing rate.

(*c.*) The question arises, Is there a legitimate prospect of our being enabled, for any prolonged period, to meet the demands of our Metallurgists and Manufacturers, by the supply of metalliferous minerals obtained from the British mines, or must we be dependent on supplies from other sources?

As an answer to these inquiries we venture to place before our readers for their serious consideration the following remarks:—

1st. The production of tin ore, from surface deposits, cannot much longer be regarded as likely to be of much value. The tin ore to be obtained from our mines *is practically inexhaustible*, but the additional supply can only be procured by extending the depth of our mines, and consequently by increasing the cost of working them. We have only one decided example of the occurrence of tin at a considerable depth below the limits of the copper-ore formation. This occurs in Dolcoath mine. The probability is, that similar conditions to those which prevail in this grand old mine will be found to continue in the adjoining mines on the north side of Carn Brea Hill. Possibly also, looking at the undulations of the Granite, as shown in the sections of the mines—so far as they have been worked in depth—a stratum of the peculiar character of the deepest beds in Dolcoath may extend round on the southern side of this hill, and give us a renewal of the stanniferous deposits in all those mines.

2nd. The hypotheses which have been put forward in relation especially

to copper ore, certainly appear to show that although an uncertain quantity of ore will probably be procurable over several areas, where productive copper mines have been worked at depths beyond those at which the mines have been abandoned, the quantity of copper ore to be obtained above 300 fathoms from the surface cannot be large. At the same time, it must not be forgotten that the copper-bearing rocks may be found in many places to dip at considerable angles, and produce deposits of copper ore of considerable value in depth. The fact that there are lodes which were at first worked for tin, which have at certain depths passed into copper lodes, and again, after being worked for many years, changed into tin-producing veins, supports the idea that below the zone now known as a stanniferous one, an unexplored stratum bearing copper may be discovered. Until this discovery is made, we must, to a considerable extent, be dependent upon Colonial and Foreign mines for the metal required to meet the demands of manufacture.

3rd. Lead, zinc, silver, &c., appear to follow the conditions which have been shown to attend the occurrence of copper ore. The ores of these metals may yet be found at greater depths than those at which they are now worked. In general lead veins have become valueless in the lower strata. Rodderup Fell vein in Alston Moor presents a remarkable exception. Mr. Wallace has described this mineral deposit with great exactness. From his description the following particulars are gathered. The strata in this locality have a very rapid inclination, and the dip must be at nearly right angles to the direction of the Great Sulphur vein, consequently on the line of Rodderup Fell vein the strata rise in a direction from the east to the west. The map given at page 462 will show that the strata on the south side is much broken by intersecting veins and beds. These numerous small *leads*, into which the veins are ramified, have been channels in which fluids have been collected, and conveyed to Rodderup Fell vein. An abrupt change from a higher to a lower level appears favourable to the deposition of lead ore. All the conditions favourable to the percolation and circulation of fluids are found connected with Rodderup Fell vein, and so combined, that they must have performed their functions in a peculiarly effective manner.

The formation of Limestone and Sandstone strata has been effected under different conditions, and with dissimilar material. They agree, however, in being oceanic sedimentary deposits, and therefore the lead ore found in the higher or the lower beds must have been held in solution, and precipitated at the time when each stratum was forming. From this fact it is rendered evident that the limits in depth of lead deposits are regulated by the relations of the Limestone or Sandstone to the oceanic waters when the ores were formed. It is not impossible that fissures containing lead ore and silver may be found in beds much deeper than those which we are now working. It may, however, with a considerable degree of safety, be predicted that the present supply of these metals will continue to require the assistance of imported ores to satisfy the demands of art and industry, until lower productive beds have been discovered.

4th. Iron ores exist in considerable quantities in several districts, and the requirements of the Ironmaster may be, for some years, met without diffi-

culty. There are, however, varieties of Foreign iron ore which will still be of importance in the production of malleable iron and steel.

5th. The cost of raising ores by the subterranean labours of our Miners has been for many years steadily increasing, and it naturally must continue to increase with the extension of mine workings, unless an improved system of mining be introduced. This applies with equal force to the mining operations for all the metallic ores.

6th. Without great improvements in the principles of mining it will not be possible to work, at a profit, many of our deeper and more extensive mines.

The following matters especially require all the attention of active minds.

(*a.*) The breaking of ground. The jointed structure of rocks must be carefully studied, that mechanical power may be used, and physical force applied, to the greatest advantage.

(*b.*) Explosives should be experimented on with every precaution, and those which give the largest result, with the smallest production of injurious elements, should be adopted.

(*c.*) Boring machinery must be simplified as much as possible: the application of the power employed to drive them should be the subject of very close attention.

(*d.*) Ventilation—either natural or artificial—should be established on the most approved principles, and carried out with the utmost economy. Pure air should *at any cost* be secured in the deepest mines.

(*e.*) The raising and lowering of the miners and the drawing of the ores are questions of the first importance. Upon the facilities afforded depends the saving of time, and the preservation of health—each of these representing an equivalent in cost.

(*f.*) The drainage of mines demands the closest attention to the machinery employed for pumping, and the engine-house of every mine should be always kept in a condition of perfect cleanliness, and every bit of exposed metal maintained in a high state of brightness. Power is always wasted where neatness and purity do not prevail.

(*g.*) Every miner should have a personal interest in the mine in which he labours. His health should be maintained in the highest state of efficiency:—and in the event of accident or of disease—occasioned by the conditions under which he labours—a provision should be made for securing the best attention to his necessities.

(*h.*) Every possible improvement should be introduced for economising the labours of the dressing-floors. If possible, every process should be carried out by mechanical appliances—and all machines should be as nearly automatic as engineering skill can render them.

(*i.*) The education of the future mine agents should be most carefully attended to, especial regard being had to their knowledge of the applications of science to the economical and useful arts. It does not appear desirable that the mind of a working man should be burdened with the details of scientific refinements, but of all the great laws, relating to the applications of the physical forces, he should have a clear conception.

(*k.*) As altogether the wealth of the Nation is increased to the extent of

£100,000,000 a year by mining operations, and its allied industries, it is of the utmost importance that every possible improvement should be adopted to support this important source of our National Wealth.

As no tradesman would have a chance of succeeding in his business, without his well-kept day book and his carefully-adjusted ledger, it is quite as important to train the miner in a careful system of registering the details of production ("Mineral Statistics"), and of recording the progress of subterranean operations by the most accurate surveys, and by preserving those "Mining Records" in some appointed place, where they can be at all times consulted not only without difficulty, but with convenience.

The matters to which especial attention must be solicited are of the utmost importance if mining in the future is to be a profitable industry. Beyond these, to enable the adventurers in our Home Mines to compete satisfactorily in the metal markets with the proprietors of Colonial and Foreign mines, and to realise a profit on the sale of their minerals, it is absolutely necessary to study the strictest economy, and to establish—beyond the risk of any failure—the highest principles of honesty in every department, directly or indirectly, connected with British mining.

BRITISH MINING.

APPENDIX.

CONTENTS OF APPENDIX.

APPENDIX.

TABLE No. 1.

Specific Gravity of Metals, Precious and Common Ores.

METALS.

	Sp. Grav.		Sp. Grav.		Sp. Grav.		Sp. Grav.
Gold	19.25	Lead	11.35	Copper	8.89	Tin	7.30
Mercury	13.26	Silver	10.47	Iron	7.78	Zinc	7.00

ORES OF PRECIOUS METALS.

	Hardness.	Sp. Gravity.
Gold—*Iron Pyrites* (mundic), associated with gold and sometimes silver	6 to 6.5	4.8 to 5.2
Magnetic Pyrites (pyrrhotine) ,, ,, ,,	3.5 4.5	4.4 ,, 4.7
Arsenical Pyrites (mispickel)	5.5 6.0	6.0 ,, 6.4
Copper Pyrites (chalcopyrite) ,,	3.5 4.0	4.1 ,, 4.3
Silver—*Horn Silver* (kerate)	1.0 1.5	5.5 ,, 5.6
Argentite (silver glance or sulphide of silver)	2.0 2.5	7.2 ,, 7.3
Stephanite (brittle sulphide of silver)	2.0, 2.5	5.2 ,, 6.3
Pyrargyrite (dark red silver ore)	2.0, 2.5	5.7 ,, 5.9
Proustite (light red silver ore)	2.0, 2.5	5.4 ,, 5.6
Mercury—*Cinnabar* (sulphide of mercury)	2.0, 2.5	8.0 ,, 8.2

COMMON ORES.

Tin.

	Hardness.	Sp. Grav.
Cassiterite (tinstone)	6.0 to 7.0	6.8 to 7.0
Tin Pyrites (bell-metal ore)	3.0 ,, 4.0	4.6 ,, 5.1

Copper.

	Hardness.	Sp. Grav.
Cuprite (ruby or red copper ore)	3.5 ,, 4.6	6.0
Melaconite (black oxide of cop.)	1.0 ,, 2.0	5.2
Malachite (green carbonate of copper)	3.5 ,, 4.0	4.0
Chessylite (blue carbonate of copper or azurite)	3.5 ,, 4.0	3.8
Tetrahedrite (grey copper ore)	2.5 ,, 3.0	5.6
Erubesite (purple or horseflesh ore)	3.0	5.0
Chalcopyrite (yellow copper ore—copper pyrites)	3.5 to 4.0	4.2
Olivenite (arseniate of copper)	3.0	4.2
Chrysocolla (silicate of copper)	2.0 to 3.0	2.2

Antimony.

	Hardness.	Sp. Grav.
Antimonite (grey antimony ore)	2.0	4.5 to 4.7
Bournanite (Endillionite)	2.5 to	
Jamesonite (sulphide of lead and antimony)	2.0 ,, 2.5	5.5

Bismuth.

	Hardness.	Sp. Grav.
Bismuthine (sulphide of bismuth)	2.0 ,, 2.5	6.4 to 6.6
Bismuth Ochre (oxide of bismuth)	—	4.3
Tetradymite (telluric bismuth)	1.5 to 2.0	7.2 to 4.3

Manganese.

	Hardness.	Sp. Grav.
Psilomelane (compact manganese ore)	5.0 to 6.0	3.7 to 4.3
Pyrolusite (red oxide of manganese)	2.0 ,, 2.5	4.7 ,, 5.0
Manganite (grey oxide of do.)	3.5 ,, 4.0	4.2 ,, 4.4
Wad (earthy manganese)	0.0 ,, 3.0	2.0 ,, 3.7
Diallogite (carbonate of manganese)	3.5 ,, 4.5	3.3 ,, 3.6
Rhodonite (bi-silicate of manganese)	5.5 ,, 7.0	3.5 ,, 3.7

Lead.

	Hardness.	Sp. Grav.
Galena (sulphide of lead)	2.0 ,, 2.5	7.2 ,, 7.6
Cerussite (white lead ore)	3.0 ,, 3.5	6.5
Anglesite (sulphate of lead)	2.7 ,, 3.0	6.[illegible] to 6.3
Pyromorphite (phosphate of lead)	3.5 ,, 4.0	7.0
Mimetene (arseniate of lead)	3.5 ,, 4.0	7.0 to 7.25

Zinc.

	Hardness.	Sp. Grav.
Calamine (carbonate of zinc)	5.0	4.5
Smithsonite (silicious oxide of zinc)	5.0	3.5
Blende (black-jack, sulphide of zinc)	3.5 to 4.0	3.9 to 4.2

Tungsten.

	Hardness.	Sp. Grav.
Wolfram (tungstate of iron)	5.0 ,, 5.5	7.2 ,, 7.5

COMMON ORES (*Continued*).

	Hardness.	Sp. Grav.
IRON.		
Magnetite (magnetic iron ore)	6·0	5·0 to 5·2
Hæmatite (red iron ore, specular iron)	6·0	5·2
Limonite (brown hæmatite)	5·0 to 5·5	3·6 to 4·0
Chalybite (spathose iron ore)	4·0	3·8
Pyrites (yellow mundic)	6·0 to 6·5	4·8 to 5·1
Leucopyrite (arsenical pyrites)	5·5 ,, 6·0	6·0
NICKEL.		
Chloanthite (white nickel—gray cobalt)	5·5	6·5
Nickelkies (copper nickel)	5·5	7·5 to 7·7

GANGUEIFEROUS MINERALS.

	Hardness.	Sp. Grav.
Sulphate of Baryta	2·5 to 3·5	4·3 to 4·8
Carbonate of ditto	3·0 ,, 3·7	4·3
Carbonate of Iron	3·0 ,, 4·5	3·7 to 3·8
Fluor-spar	4·0	3·0 to 3·3
Quartz, or Silica	7·0	2·6 ,, 2·7
Carbonate of Lime	2·5 to 3·5	2·6 ,, 3·8

VEINIFEROUS. (FRAGMENTS *or Brescia of adjacent Rocks.*)

	Sp. Grav.	
Granite	2·4 to	2·7
Gneiss	2·4	2·7
Mica Slate	2·6	2·9
Syenite	2·7	3·0
Hornblende	3·0	3·1
Greenstone Trap	2·7	2·9
Basalt	2·6	3·1
Porphyry	2·3	2·7
Talcose Slate	2·6 to	2·8
Clay-Slate (*Killas*)	2·5	2·8
Chloritic Slate	2·7	2·8
Serpentine	2·5	2·7
Limestone and Dolomite	2·5	2·9
Sandstone	1·9	2·7
Shale, or Schiefer	2·8	

TABLE No. 2.

SHOWING THE UNDERLIE AND PERPENDICULAR OF LODES, IN FEET AND INCHES, TO EVERY DEGREE OF THE QUADRANT IN SIX FEET. (Page 662.)

Degrees.	Base. Feet.	Base. Inches.	Perp. Feet.	Perp. Inches.	Degrees.	Degrees.	Base. Feet.	Base. Inches.	Perp. Feet.	Perp. Inches.	Degrees.
0	6	0	0	0	90	23	5	6¼	2	4	67
1	6	0	0	1¼	89	24	5	6	2	5¼	66
2	5	11¾	0	2½	88	25	5	5¼	2	6½	65
3	5	11⅝	0	3¾	87	26	5	4¾	2	7⅝	64
4	5	11⅝	0	5	86	27	5	4⅛	2	8⅝	63
5	5	11½	0	6¼	85	28	5	3⅝	2	9⅞	62
6	5	11⅜	0	7½	84	29	5	3	2	11	61
7	5	11¼	0	8¾	83	30	5	2⅜	3	0	60
8	5	11⅛	0	10	82	31	5	1¾	3	1	59
9	5	11	0	11	81	32	5	1	3	2⅛	58
10	5	10⅞	1	0½	80	33	5	0¼	3	3¼	57
11	5	10⅝	1	1¾	79	34	4	11¼	3	4⅜	56
12	5	10⅜	1	3	78	35	4	11	3	5¼	55
13	5	10⅛	1	4	77	36	4	10¼	3	6¼	54
14	5	9⅞	1	5⅜	76	37	4	9½	3	7¼	53
15	5	9⅝	1	6⅝	75	38	4	8⅞	3	8¼	52
16	5	9¼	1	8	74	39	4	8	3	9⅝	51
17	5	8⅞	1	9	73	40	4	7½	3	10⅝	50
18	5	8½	1	10¼	72	41	4	6½	3	11⅛	49
19	5	8⅛	1	11⅜	71	42	4	5⅝	4	0	48
20	5	7⅝	2	0⅝	70	43	4	4¾	4	1	47
21	5	7⅛	2	1¾	69	44	4	4	4	2	46
22	5	6¾	2	3	68	45	4	3	4	3	45
Degrees.	Perp. Feet.	Perp. Inches.	Base. Feet.	Base. Inches.	Degrees.	Degrees.	Perp. Feet.	Perp. Inches.	Base. Feet.	Base. Inches.	Degrees.

EXAMPLE.—To Horizontal Quadrant, angle down, 25°; length 9 fms. 3 ft. Opposite 25° in this Table is 5 ft. 5¼ in. × 9 fm. 3 ft. = 54 7⅛. For Perpendicular, 2 ft. 6½ in. × 9 fm. 3 ft. = 24 0⅜.

This Table is calculated for the Quadrant taking its angle from the horizon.

N.B. When the angle exceeds 45°, read from the foot of the Table, and take the Base and Perpendicular as marked there.

TABLE No. 3.

An Account of the Annual Produce of the Tin Mines of Cornwall from the Years 1750 to 1817.

Year.	Blocks.	Tons.	Average Price per Cwt.	Year.	Blocks.	Tons.	Average Price per Cwt.
	No.		£ s. d.		No.		£ s. d.
1750	18,698	2,876	3 4 10½	1784	17,456	2,685	3 10 6
1751	14,776	2,273	3 5 1½	1785	18,753	2,885	3 12 0
1752	16,574	2,550	3 7 1½	1786	22,096	3,399	3 12 0
1753	16,358	2,516	3 8 0	1787	20,824	3,204	3 12 0
1754	17,708	2,724	3 7 10½	1788	21,790	3,352	3 6 6
1755	17,924	2,757	3 7 0	1789	22,132	3,405	3 2 6
1756	18,033	2,774	3 2 7½	1790	20,753	3,193	3 12 6
1757	17,881	2,752	2 19 3	1791	22,561	3,470	3 19 6
1758	17,681	2,720	2 16 3	1792	24,763	3,809	4 12 6
1759	17,140	2,637	2 16 0	1793	20,805	3,202	4 18 0
1760	17,662	2,717	2 16 0	1794	21,793	3,351	4 15 6
1761	15,571	2,395	2 19 10½	1795	22,353	3,440	4 13 0
1762	16,801	2,584	3 4 9	1796	19,902	3,061	4 16 6
1763	17,786	2,736	3 8 10½	1797	21,063	3,240	4 17 0
1764	16,997	2,618	3 9 0	1798	18,332	2,820	4 14 0
1765	17,923	2,757	3 9 0	1799	18,603	2,862	4 17 0
1766	19,861	3,055	3 9 0	1800	16,397	2,522	5 1 0
1767	18,529	2,850	3 9 0	1801	14,552	2,328	5 5 0
1768	17,334	2,667	3 9 0	1802	16,420	2,627	5 8 6
1769	18,838	2,898	3 9 0	1803	18,212	2,914	5 9 0
1770	19,355	2,977	3 6 6	1804	18,716	2,993	5 9 0
1771	18,349	2,823	3 5 0	1805	17,139	2,742	5 12 6
1772	20,531	3,159	3 3 3	1806	17,846	2,855	6 0 6
1773	18,540	2,852	2 14 0	1807	15,168	2,426	5 17 6
1774	15,975	2,458	2 12 6	1808	14,589	2,330	5 14 0
1775	17,024	2,619	3 0 0	1809	15,690	2,508	6 2 0
1776	17,240	2,652	2 19 9	1810	12,528	2,006	7 17 0
1777	18,010	2,770	2 19 6	1811	14,675	2,384	7 1 6
1778	16,302	2,515	3 0 6	1812	14,606	2,373	6 8 0
1779	17,411	2,678	3 0 0	1813	14,306	2,324	6 14 0
1780	19,052	2,925	3 1 3	1814	16,069	2,611	7 16 6
1781	16,969	2,610	3 4 3	1815	18,101	2,941	7 [illegible] 6
1782	16,548	2,546	3 10 0	1816	20,608	3,348	5 14 6
1783	16,705	2,570	3 10 0	1817	25,379	4,120	4 13 6

TABLE No. 4.

An Account of the Produce of the Tin Mines of Cornwall and Devon, distinguishing Grain and Common Tin, and Prices in the Market from 1818 to 1837.

Year.	Blocks. Common.	Blocks. Grain.	Total Blocks.	Tons.	Price of Refined Tin in Wales.	Price of Common Tin in Cornwall.
	No.	No.	No.		s. d.	s. d.
1818	19,468	3,755	23,243	4,066	88 0	84 9
1819	17,091	1,856	18,947	3,315	78 6	75 3
1820	15,338	1,746	17,084	2,990	76 9	73 3
1821	17,022	2,251	19,273	3,373	81 0	75 8
1822	16,574	2,157	18,731	3,278	100 0	95 6
1823	21,662	2,415	24,077	4,213	105 3	94 9
1824	25,837	2,765	28,602	5,005	93 3	88 0
1825	23,066	1,836	24,902	4,358	94 6	91 4
1826	24,787	1,512	26,299	4,603	82 3	77 0
1827	29,965	1,779	31,744	5,555	83 3	76 0
1828	26,386	1,792	28,178	4,931	81 9	73 3
1829	23,929	1,408	25,337	4,434	80 3	74 0
1830	23,593	1,799	25,392	4,444	78 0	73 9
1831	23,194	1,374	24,568	4,300	83 0	73 6
1832	23,351	1,351	24,702	4,323	78 0	72 9
1833	21,994	1,237	23,231	4,065	78 9	72 9
1834	21,397	1,395	22,792	3,989	88 6	78 0
1835	22,637	1,523	24,160	4,228	99 0	91 6
1836	21,477	1,692	23,169	4,054	114 3	109 6
1837	25,891	1,482	27,373	4,790	93 3	88 0

Note.—A block of tin weighs 3 cwts. 2 qrs.

TABLE No. 5.

GENERAL STATEMENT OF THE TIN TRADE OF CORNWALL FROM 1750 TO 1799 INCLUSIVE.

Years of Peace and War.		Quantity Raised, Grain and Common. Blocks. 6½ to	Tons. 1	Exported to Europe, Africa, and America. Blocks.	Tons.	Average Price per Cwt. com. Tin, exclusive of Prince's Duty, &c. £	s.	d.
Peace.	1750	18,698	2,876	For 33 years no Account of the Exports obtained from the Custom House.		3	4	10
	1751	14,776	2,273			3	5	1
	1752	16,574	2,550			3	7	1
	1753	16,358	2,516			3	8	0
	1754	17,708	2,724			3	7	10
	1755	17,924	2,757			3	7	0
War.	1756	18,033	2,774			3	2	7
	1757	17,887	2,752			2	19	3
	1758	17,681	2,720			2	16	3
	1759	17,140	2,637			2	16	0
	1760	17,662	2,717			2	16	0
	1761	15,571	2,395			2	19	10
	1762	16,801	2,584			3	4	9
Peace.	1763	17,786	2,736			3	8	10
	1764	16,997	2,618			3	9	0
	1765	17,923	2,757			3	9	0
	1766	19,861	3,055			3	9	0
	1767	18,529	2,850			3	9	0
	1768	17,334	2,667			3	9	0
	1769	18,838	2,898			3	9	0
	1770	19,355	2,977			3	6	6
	1771	18,349	2,823			3	5	0
	1772	20,531	3,159			3	3	3
War.	1773	18,540	2,852			2	14	0
	1774	15,975	2,458			2	12	6
	1775	17,024	2,619			3	0	0
	1776	17,240	2,652			2	19	6
	1777	18,010	2,770			2	19	6
	1778	16,302	2,515			3	0	6
	1779	17,411	2,678			3	0	0
	1780	19,022	2,926			3	1	3
	1781	16,969	2,610			3	4	3
Peace.	1782	16,548	2,546			3	10	0
	1783	16,705	2,570	10,988	1,690	3	10	0
	1784	17,456	2,685	10,169	1,564	3	10	6
	1785	18,753	2,885	13,022	2,003	3	12	0
	1786	22,096	3,399	15,265	2,348	3	12	0
	1787	20,824	3,204	14,498	2,233	3	12	0
	1788	21,790	3,352	14,992	2,306	3	6	6
Peace.	1789	22,132	3,405	13,760	2,117	3	2	6
	1790	20,753	3,193	10,569	1,626	3	5	0
	1791	22,561	3,470	12,538	1,929	3	10	0
War.	1792	24,763	3,809	11,141	1,714	4	1	8
	1793	20,805	3,202	7,114	1,095	3	15	7
	1794	21,793	3,351	8,417	1,295	3	12	5
	1795	22,353	3,440	10,246	1,576	3	10	8
	1796	19,902	3,061	7,871	1,212	3	15	5
	1797	21,063	3,240	5,817	895	3	10	6
	1798	18,332	2,820	9,824	1,511	3	12	8
	1799	18,603	2,862	7,644	1,176	4	3	0

APPENDIX.

TABLE No. 6.

AN ACCOUNT OF THE TIN ORE AND METALLIC TIN OBTAINED FROM THE MINES OF CORNWALL AND DEVON IN EACH YEAR SINCE 1848.

Year.	Tin Ores. (Black Tin.)	Metallic Tin. (White Tin.)	Year.	Tin Ores. (Black Tin.)	Metallic Tin. (White Tin.)
	Tons.	Tons.		Tons.	Tons.
1848	10,176	—	1866	15,080	9,990
1849	10,719	—	1867	13,649	8,700
1850	10,383	—	1868	13,953	9,300
1851	9,455	—	1869	14,725	9,760
1852	9,672	—	1870	15,234	10,200
1853	8,866	5,763	1871	16,272	10,900
1854	8,747	5,947	1872	14,266	9,500
1855	8,947	6,000	1873	14,885	9,972
1856	9,350	6,177	1874	14,039	9,942
1857	9,783	6,582	1875	13,995	9,614
1858	10,618	6,920	1876	13,688	8,500
1859	10,670	7,100	1877	14,142	9,500
1860	10,462	6,695	1878	15,045	10,106
1861	11,640	7,450	1879	14,665	9,532
1862	14,127	8,476	1880	13,737	8,918
1863	15,157	10,006	1881	12,900	8,600
1864	15,211	10,108	1882	14,044	9,157
1865	15,686	10,039			

TABLE No. 7.

AVERAGE PRICE (PER TON) OF TIN ORE AND METALLIC TIN IN EACH YEAR SINCE 1854.

Year.	Tin Ore.			Metallic Tin.			Year.	Tin Ore.			Metallic Tin.		
	£	s.	d.	£	s.	d.		£	s.	d.	£	s.	d.
1854	64	0	0	114	0	0	1868	55	4	0	98	0	0
1855	68	0	0	119	0	0	1869	69	16	0	123	2	0
1856	71	0	0	133	0	0	1870	75	3	0	127	8	6
1857	76	0	0	136	0	0	1871	78	12	6	137	10	0
1858	63	4	0	119	2	2	1872	87	7	0	152	15	0
1859	74	15	0	130	18	3	1873	78	1	0	133	7	0
1860	71	11	6	136	3	1	1874	56	3	0	108	8	0
1861	62	6	8	122	5	0	1875	52	11	6	90	2	0
1862	59	14	0	116	0	0	1876	43	18	0	79	10	2
1863	63	12	0	117	0	0	1877	40	10	0	73	3	6
1864	60	17	6	107	1	0	1878	35	5	6	65	12	3
1865	55	6	0	96	15	0	1879	40	0	0	72	6	0
1866	48	10	9	88	12	6	1880	49	0	0	91	5	0
1867	50	18	0	91	17	3	1881	54	0	0	97	9	3

TABLE No. 8.

An Account of Tin shipped from Cornwall by the East India Company for China.

		Cwts.	qrs.	lbs.
1762.	401 boxes of Cornish grain tin	1,920	3	27
	187 „ common tin	599	1	12
1763.	141 „ Cornish grain tin	712	2	9
1766.	40 „ common tin	206	1	24
1768.	200 „ „ „	1,014	3	4
		4,454	0	20

		Tons.
1789.	In blocks, ingots, and caps, shipped by the Company	50
	Price £68 to £69 10s. per ton.	
	In private trade	38
	Price from £66 to £69 per ton.	
1790.	Shipped by the Honourable East India Company in ingots for China	775
	Shipped for Madras, Bengal, and Bombay, by way of trial	25

TABLE No. 9.

It appears that since the opening of the Tin Trade from the County of Cornwall to China, in 1789, the quantity of Tin raised in the County from that period to 1816 inclusive, 28 years, is 78,242 tons; deducting Prince's Duty, Shipping Charges, &c., has produced a sum to the Tin Interest of the County, equal to the quantity raised the preceding 39 years, say, 107,536 tons. Further, that the average price of Common Tin sold to the East India Company for 28 years, deducting all the charges whatever, estimated at £9 6s. 2d. per ton, is equal to the average price of all the Common Tin raised in Cornwall for 39 years previous to the commencement of the trade to China. GEORGE UNWIN.

An Account of the Quantity of Tin exported from Great Britain in the following Years, distinguishing the Countries to which it has been exported.

Countries.	1788.			1789.			1790.			5th Jan. to July 5th, 1791.			1791.		
	Cwts.	qr.	lb	Cwts.	qr.	lb	Cwts.	qr.	lb.	Cwts.	qr.	lb.	Cwt.	qr.	lb.
DENMARK and NORWAY	372	1	15	906	1	0	472	0	6	257	2	0	3,670	3	14
Russia	8,028	1	16	6,687	3	21	5,051	2	8	686	2	6	2,504	0	13
Sweden	986	3	20	900	0	7	179	1	11	313	0	6	1,058	0	2
Poland	324	2	7	3	1	21	34	3	24	38	2	24	39	0	17
Prussia	401	1	0	806	2	22	356	3	7	258	2	0	744	1	3
Germany	2,719	0	0	4,972	3	1	2,996	1	5	1,315	2	8	2,129	3	27
Holland	5,217	0	25	7,817	3	19	7,078	0	8	2,800	0	18	4,672	0	9
Austrian Flanders	1,662	1	12	607	1	0	581	0	1	418	3	5	793	2	13
French Flanders and France	13,339	2	10	5,426	1	16	2,749	3	20	2,342	0	22	6,434	2	13
Portugal	1,019	0	0	1,600	1	19	629	1	0	316	1	0	853	0	23
Spain	2,555	0	18	3,327	1	0	1,373	1	26	1,800	0	25	3,164	2	2
Gibraltar	9	2	14	0	0	0	50	0	0	76	0	0	76	0	0
Italy and Venice	5,965	0	10	3,461	1	6	5,293	2	17	2,879	3	6	4,515	0	16
Turkey	2,368	0	10	4,232	3	19	4,396	0	14	2,074	3	10	6,434	1	3
Ireland	739	1	9	731	3	9	979	0	9	551	0	12	936	3	18
Guernsey and Jersey	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
Africa	77	0	0	62	0	0	129	3	8	40	0	0	48	3	16
West Indies	155	1	8	118	0	17	72	1	13	39	2	14	345	2	17
States of America	55	1	18	75	3	16	109	3	27	205	2	7	376	0	7
British Continental Colonies	139	2	23	616	0	0	0	0	0	0	0	0	0	0	0
	46,136	1	19	42,344	1	25	32,534	0	7	16,421	1	23	38,597	1	17
INDIA and CHINA	300	0	0	1,960	2	22	25,674	2	23	13,754	1	22	13,754	1	22
	46,436	1	19	44,305	0	19	58,208	3	2	30,175	3	17	52,711	3	11

		Cwts.	qrs.	lbs.
We exported in the Year	1783	33,814	0	0
„ „ „	1784	31,288	0	0
„ „ „	1785	40,062	0	0
„ „ „	1786	46,965	0	0
„ „ „	1787	44,612	0	0

The Annual Quantity of Tin raised in Cornwall, about 3,400 Tons, and the Home Consumption did not exceed 1,000 Tons.

TABLE No. 10.

TIN SUPPLIED TO EAST INDIA COMPANY BY CORNWALL UNDER THE STOCKING SYSTEM:—

From		To		Tin.			
				Tons	cwts.	qrs.	lbs.
October,	1793	April,	1794	1,232	16	2	17
December,	1794	May,	1795	1,202	5	0	26
January,	1796	June,	1796	1,202	12	1	14
December,	1796	April,	1797	1,062	4	0	9
November,	1797	March,	1798	1,229	16	1	15
December,	1798	May,	1799	802	17	1	24
November,	1799	April,	1800	687	10	3	7
October,	1800	February,	1801	701	9	2	23
November,	1801	March,	1802	302	1	3	27
September,	1802	March,	1803	394	11	1	16
November,	1803	April,	1804	595	14	3	1
November,	1804	March,	1805	851	19	1	9
February,	1806	March,	1806	375	13	2	0
January,	1807	March,	1807	642	16	1	21
December,	1807	April,	1808	692	16	0	27
December,	1808	May,	1809	841	15	1	23
January,	1810	March,	1811	379	2	0	9
October,	1811	March,	1812	449	0	1	5
October,	1812	February,	1813	856	1	2	4
November,	1813	February,	1814	619	16	3	23
December,	1814	February,	1815	472	7	3	16
February,	1816	—		349	14	1	4
October,	1816	March,	1817	406	7	0	21
March,	1821	—		48	15	2	23
January,	1822	—		126	18	0	5
February,	1822	—		150	0	1	14
June,	1822	—		28	18	3	7

TABLE No. 11.

PRODUCTION OF COPPER ORE IN CORNWALL FROM 1726 TO 1775. (*Pryce.*)

				Tons.		£	s.	d.	
1726 inclusive, to end of	1735	was		64,800	at average price of	7	1	10	per ton.
1736	1745	,,		75,520		7	8	6	
1746	1755	,,		98,790	,,	7	8	0	,,
1756	1765	,,		169,690	,,	7	6	0	,,
1766	1775	,,		264,273	,,	6	14	6	,,

				£			£
From 1726 to 1735	Yearly value			47,350	Total of years	=	473,500
,, 1736 ,, 1745	,,			56,010	,,	=	565,616
,, 1746 ,, 1755	,,			73,145	,,	=	731,457
,, 1756 ,, 1765	,,			124,304	,,	=	1,243,045
,, 1766 ,, 1775	,,			177,833	,,	=	1,788,337

TABLE No. 12.

AN ACCOUNT OF THE ANNUAL PRODUCE OF COPPER ORE FROM CORNWALL FROM 1727 TO 1771.

Year.	Copper Ore.	Year.	Copper Ore.	Year.	Copper Ore.
	Tons.		Tons.		Tons.
1727	6,700	1742	6,050	1757	17,000
1728	6,800	1743	7,040	1758	15,009
1729	6,870	1744	7,230	1759	16,700
1730	6,900	1745	6,700	1760	15,780
1731	7,000	1746	7,000	1761	17,004
1732	7,293	1747	4,900	1762	16,054
1733	7,000	1748	6,000	1763	17,898
1734	6,000	1749	7,200	1764	21,489
1735	5,240	1750	9,400	1765	16,774
1736	8,000	1751	11,000	1766	21,251
1737	9,000	1752	12,050	1767	18,502
1738	10,000	1753	13,000	1768	23,671
1739	11,000	1754	14,000	1769	26,655
1740	5,000	1755	14,240	1770	30,776
1741	5,500	1756	16,000	1771	27,896

TABLE No. 13.

THE ANNUAL PRODUCE OF THE COPPER MINES OF CORNWALL SOLD AT TICKETINGS, GIVING THE ORE, THE MONEY VALUE, AND STANDARD, FROM 1772 TO 1799.

Year.	Copper Ore.	Copper.	Amount. Money Value.	Standard	Year.	Copper Ore.	Copper.	Amount. Money Value.	Standard
	Tons.	Tons.	£	£		Tons.	Tons.	£	£
1772	27,965	3,556	189,505	81	1786	39,895	4,787	237,237	75
1773	27,663	3,320	148,431	70	1787	38,047		190,738	67
1774	30,254	3,630	162,000	68	1788	31,541		150,303	57
1775	29,966	3,596	192,000	78	1789	33,281		184,308	63
1776	29,433	3,532	191,590	79	1790	Not obtainable.			
1777	28,216	3,386	177,000	77	1791				
1778	24,706	2,965	140,536	72	1792				
1779	31,115	3,734	180,906	73	1793				
1780	24,433	2,932	171,231	83	1794	42,816		320,875	88
1781	28,749	3,450	178,789	77	1795	43,589		326,189	87
1782	28,122	3,375	152,434	70	1796	43,313		356,564	93
1783	35,799	4,296	219,937	76	1797	47,909	5,210	377,838	96
1784	36,601	4,392	209,132	72	1798	51,358	5,600	422,633	—
1785	36,959	4,434	205,451	71	1799	51,273	4,923	469,664	121

TABLE No. 14.

THE ANNUAL SALES OF COPPER ORES AT TICKETINGS SINCE 1800, GIVING THE QUANTITY OF COPPER, THE PERCENTAGE PRODUCED, AND STANDARD.

Year.	Copper Ore.	Copper.	Produce.	Standard.	Year.	Copper Ore.	Copper.	Produce.	Standard.
	Tons.	Tons.		£ s. d.		Tons.	Tons.		£ s. d.
1800	55,981	5,187	9¼	133 3 6	1843	153,668	10,926	$7\frac{1}{2}\frac{1}{16}$	110 0 0
1801	56,611	5,267	9¼	117 5 0	1844	152,667	11,246		109 0 0
1802	53,937	5,228	9⅝	110 18 0	1845	162,557	12,883		103 10 0
1803	60,566	5,615	9¼	122 0 0	1846	150,431	11,850		106 8 0
1804	64,637	5,375	8⅜	136 5 0	1847	148,674	11,966		103 12 0
1805	78,452	6,234	7⅞	169 16 0	1848	155,616	12,869		97 7 0
1806	79,269	6,863	8⅝	138 5 0	1849	144,983	12,052		92 11 0
1807	71,694	6,716	9⅜	120 0 0	1850	150,890	11,824		103 19 0
1808	67,867	6,795	10	100 17 0	1851	154,299	12,199		101 0 0
1809	76,245	6,821	8⅞	143 12 0	1852	152,802	11,706		106 12 0
1810	66,088	5,683	8½	132 5 0	1853	180,095	11,839		136 16 0
1811	66,768	6,141	9⅛	120 10 0	1854	180,687	11,779		140 2 0
1812	71,547	6,720	9⅜	111 0 0	1855	188,969	12,242		141 10 0
1813	74,047	6,918	9¼	115 7 0	1856	209,305	13,274		140 0 0
1814	74,322	6,369	8½	130 12 0	1857	198,697	13,088		139 6 0
1815	78,483	6,526	8¼	117 16 6	1858	183,292	11,764		135 1 0
1816	77,334	6,697	8⅝	98 13 0	1859	183,944	11,888		133 0 0
1817	76,701	6,498	8½	108 10 0	1860	180,448	11,769		133 8 0
1818	86,174	6,849	7⅞	134 15 0					
1819	88,736	6,804	7⅝	127 10 0	1861	180,778	11,486		130 15 0
1820	91,473	7,508	8⅛	113 15 0	1862	183,313	11,566		123 16 0
1821	98,426	8,515	8⅝	103 0 0	1863	169,971	10,896		119 5 0
1822	104,523	9,140	8¾	104 0 0	1864	165,601	10,273	1/16	127 19 0
1823	95,750	7,928	8¼	109 18 0	1865	159,409	9,750		122 12 0
1824	99,700	7,824	7⅞	110 0 0	1866	138,141	8,799		109 7 0
1825	107,454	8,226	7⅝	114 0 0					
1826	117,308	9,026	7⅝	123 3 0	1867	119,766	8,027		110 9 0
1827	126,710	10,311	8⅛	106 1 0	1868	117,262	7,667		107 10 0
1828	130,366	9,921	7⅝	112 7 0	1869	94,606	6,544		101 6 0
1829	124,502	9,656	7¾	109 14 0	1870	81,278	5,606		98 1 0
1830	133,904	10,748	8	106 5 0	1871	71,118	4,682		102 10 0
1831	144,402	12,044	8⅜	100 0 0	1872	65,386	4,129		119 18 0
1832	137,357	11,947	8⅝	100 0 0					
1833	138,300	11,191	8⅛	111 0 0	1873	55,095	3,782		102 11 0
1834	143,296	11,225	7⅞	114 0 0	1874	49,175	3,542		103 0 0
1835	150,617	12,270	8⅛	106 11 0	1875	51,122	3,521		113 7 0
1836	140,981	11,647	8¼	115 12 0	1876	57,985	3,841		107 9 0
1837	140,753	10,823	7⅝	119 0 0	1877	53,785	3,714		97 6 0
1838	145,688	11,577	7⅞	109 0 0	1878	47,591	3,390		88 4 0
1839	159,551	12,450	7¾	110 0 0					
1840	147,266	11,037	7½	108 10 0	1879	42,094	2,889		89 5 0
1841	147,846	9,987	7¾	119 0 0	1880	40,311	2,754		95 0 0
1842	154,180	9,896	$7\frac{1}{2}\frac{1}{16}$	120 0 0	1881	40,584	2,681		94 8 0

TABLE No. 15.
Copper Ore Sales at Swansea Ticketings from British, Colonial, and Foreign, from 1804 to 1863.

Year.	British Mines.				Colonial and Foreign Mines.	Total Sales, British and Foreign.
	English.	Welsh.	Irish.	Total.		
	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
1804	—	52	—	52	—	—
1806	—	41	62	103	—	—
1807	—	68	810	878	—	—
1808	—	312	1,391	1,703	—	—
1809	—	240	530	770	—	—
1810	—	400	603	1,003	—	—
1811	—	88	68	156	—	—
1812	—	622	120	742	—	—
1813	—	442	213	655	—	—
1814	—	321	429	750	—	—
1815	77	1,079	700	1,856	—	—
1816	35	600	673	1,308	—	—
1817	—	422	9	431	—	—
1818	317	247	349	913	—	—
1819	1,796	90	1,531	3,417	—	—
1820	1,408	124	2,200	3,732	—	—
1821	957	191	2,040	3,188	—	—
1822	521	412	1,923	2,856	—	—
1823	633	564	3,673	4,870	—	—
1824	436	358	4,471	5,265	—	—
1825	2,061	1,191	5,350	8,602	—	—
1826	505	1,115	4,271	5,891	—	—
1827	508	1,140	7,383	9,031	—	—
1828	320	3,555	8,510	12,385	199	12,584
1829	720	6,076	7,044	13,840	668	14,508
1830	415	1,788	9,115	11,318	934	12,252
1831	540	1,442	9,707	11,689	918	12,607
1832	646	3,184	11,399	15,229	579	15,808
1833	361	1,786	11,293	13,440	1,059	14,499
1834	377	3,336	17,280	20,993	2,077	23,070
1835	268	3,770	22,123	26,161	6,758	32,919
1836	535	1,698	21,013	23,246	9,046	32,292
1837	179	2,216	22,306	24,701	14,521	39,222
1838	964	3,410	22,161	26,535	19,868	46,403
1839	1,812	2,637	23,613	28,062	24,092	52,154
1840	752	1,525	20,166	22,443	35,354	57,797
1841	705	1,180	14,321	16,206	41,364	57,570
1842	1,910	857	15,253	18,020	44,392	62,412
1843	756	1,133	17,600	19,489	40,759	60,248
1844	430	700	20,063	21,193	45,491	66,684
1845	622	1,914	19,647	22,183	46,643	68,826
1846	549	1,035	17,553	19,137	39,348	58,485
1847	406	340	14,373	15,119	35,700	50,819
1848	268	231	12,169	12,768	36,728	49,496
1849	734	296	9,934	10,964	32,729	43,693
1850	1,302	144	10,584	12,030	29,556	41,586
1851	468	339	11,661	12,468	24,773	37,241
1852	641	502	10,962	12,105	19,549	31,654
1853	498	553	10,035	12,086	20,887	32,973
1854	737	283	11,288	12,208	24,612	36,820
1855	1,088	173	12,459	13,720	30,500	44,220
1856	681	140	11,395	12,216	30,026	42,242
1857	827	183	8,904	9,914	27,657	37,571
1858	1,064	1,697	11,215	13,976	23,222	37,198
1859	1,514	5,778	12,010	19,302	23,900	43,202
1860	1,515	217	16,297	18,029	21,619	39,648
1861	1,293	267	14,801	16,361	21,294	37,655
1862	1,815	220	14,364	16,399	23,895	40,294
1863	1,676	75	14,751	16,094	27,094	43,596

TABLE No. 16.

TOTAL OF ANNUAL COPPER SALES AT SWANSEA TICKETINGS SINCE 1863,

	Tons.	Tons.		£ s. d.
1861	37,655	5,306	$14\frac{1}{16}$	107 2 0
1862	40,294	5,969	$14\frac{3}{4}\frac{1}{16}$	101 7 0
1863	43,596	6,196	$12\frac{1}{8}\frac{1}{16}$	98 18 0
1864	32,413	4,632	$14\frac{1}{4}$	103 3 0
1865	25,217	3,791	15	93 17 0
1866	36,158	5,218	$14\frac{3}{8}\frac{1}{16}$	89 4 0
1867	31,532	5,132	$16\frac{1}{4}$	86 0 0
1868	34,166	5,157	$15\frac{1}{16}$	86 3 0
1869	28,007	3,912	$13\frac{7}{8}\frac{1}{16}$	82 19 0
1870	14,534	2,329	16	47 6 0
1871	25,724	4,419	$17\frac{1}{8}\frac{1}{16}$	79 13 0
1872	24,688	4,230	$17\frac{1}{8}$	99 18 0
1873	26,4 7	4,639	$17\frac{1}{2}\frac{1}{16}$	90 14 0
1874	31,439	5,597	$17\frac{3}{4}\frac{1}{16}$	89 0 0
1875	23,053	4,298	$18\frac{3}{8}$	93 3 0
1876	34,256	5,812	$17\frac{1}{4}$	87 11 0
1877	49,416	6,258	$12\frac{5}{8}$	82 19 0
1878	35,579	2,910	$8\frac{1}{8}\frac{1}{16}$	82 10 0
1879	25,452	2,601	$10\frac{1}{8}\frac{1}{16}$	78 11 0
1880	24,396	2,160	$8\frac{7}{8}$	85 8 0
1881	19,717	1,666	$8\frac{3}{8}\frac{1}{16}$	84 9 0

The transactions of the CONSOLIDATED MINES for eighteen years ending 1836, from Sir Charles Lemon's paper in the "Statistical Society's Journal," vol. i. p. 771.

TABLE No. 17.

Year.	Capital and Compound Interest.	Cost.	Lord's Dues.	Value of Ores.	Tons of Ore.	Wages.
	£	£	£	£	Tons.	£
1819	15,267	—	—	—	—	—
1820	36,644	—	—	—	—	—
1821	18,223	—	—	—	—	—
1822	3,506	—	—	—	—	—
1823	3,479	69,836	3,478	83,438	11,532	43,716
1824	13,001	84,081	4,584	110,036	14,980	47,885
1825	2,768	95,451	4,971	119,312	13,379	53,275
1826	1,985	82,865	3,848	92,355	13,872	43,200
1827	1,726	81,322	4,108	98,601	13,637	41,439
1828	1,199	69,825	4,103	96,313	13,262	37,568
1829	340	68,177	3,673	88,171	12,578	38,183
1830	Capital repaid.	69,897	3,795	91,092	13,512	39,304
1831	—	75,290	4,310	103,451	15,292	43,410
1832	—	83,472	4,791	115,000	15,676	47,051
1833	—	89,696	5,967	143,227	18,191	51,844
1834	—	88,956	5,652	135,670	20,022	42,690
1835	—	90,216	5,607	134,574	19,619	53,787
1836	—	102,007	6,071	145,717	18,499	61,257
					214,045	644,699

TABLE No. 18.

PRIVATE CONTRACT PURCHASES, SO FAR AS RETURNS CAN BE OBTAINED FROM 1832 TO 1862.

		Ore.	Copper.	
1832			441	Ore not given.
1833		2,500	540	Ore, Vivian's purchase only.
1834		4,708	469	
1835		2,829	546	
1836		5,338	535	
1837	The British, Colonial, and the Foreign ores remain in these returns undivided.	7,579	720	
1838		6,806	662	
1839		11,614	1,478	Ore of 5 companies; metal of 7 comps.
1840		18,085	2,043	,, 6 7
1841		13,313	2,192	8
1842		21,658	3,471	7
1843		20,341	3,739	8
1844		29,818	4,108	10 ,, including 741 tons of metal from Anglesea ore.
1845	British . . . . 14,118; Foreign and Colonial 7,342	21,452	4,099	Copper includes 722 tons made at Amlwch; the ore not given.
1846	British . . . . 10,137; Foreign and Colonial 7,836	17,973	3,902	Copper includes 664 tons at Amlwch; the ore not given.
1847	British . . . . 6,458; Foreign and Colonial 3,002	9,410	1,953	Copper includes 535 tons Amlwch, the ore of which is not given.
1848	British, Foreign, and Colonial not distinguished.	13,067	1,577	Including Amlwch copper 432 tons.
1849	British, Foreign, and Colonial cannot be separated; ore includes 80 tons of copper not given.	13,492	3,881	Including Amlwch copper 614 tons, and 1,649 tons of copper from Foreign ores not given.
1850	British and Foreign uncertain. After this date the relative quantities of the British and Foreign copper cannot be determined.	16,434	4,506	Including 671 tons Amlwch, and 1,406 Foreign copper; ore not given.
1851		12,295	4,001	Including 734 tons Amlwch, and 1,440 tons Foreign copper; ore not given.
1852		13,889	3,833	Including 517 tons Amlwch, and 937 tons of Foreign copper; ore not given.
1853		24,633	5,861	Including 586 tons Amlwch and 1,689 tons copper (British or Foreign not stated); ore not given
1854		17,366	5,425	Including 572 tons Amlwch copper.
1855		27,302	7,238	,, 540 ,, ,,
1856		29,423	7,476	,, 572 ,, ,, (Grenfell & Co. and Ravenhead Co. not included.
1857		29,809	10,673	Including 524 tons Amlwch copper.
1858		39,908	13,584	,, 465 ,,
1859		39,269	12,359	,, 621 ,,
1860		40,383	10,955	,, 787 ,,
1861		47,496	13,243	,, 562 ,,
1862		35,160	11,304	,, 829 ,,

TABLE No. 19.

AVERAGE PRICES PER TON OF COPPER ORE AND OF METALLIC COPPER IN EACH YEAR SINCE 1855.

Year.	Copper Ore.			Metallic Copper.			Year.	Copper Ore.			Metallic Copper.		
	£	s.	d.	£	s.	d.		£	s.	d.	£	s.	d.
1855	6	8	0	129	0	0	1869	4	3	6	77	10	0
1856	6	2	6	123	0	0	1870	4	3	0	72	13	0
1857	6	8	6	124	0	0	1871	3	18	6	77	10	0
1858	5	18	6	108	0	0	1872	4	13	6	104	5	0
1859	5	17	6	112	7	6	1873	4	8	0	95	18	0
1860	5	19	0	109	13	10	1874	4	5	0	89	12	0
1861	5	16	0	102	12	0	1875	5	0	0	90	0	0
1862	5	14	0	100	12	0	1876	4	17	0	83	6	2
1863	4	19	0	98	17	0	1877	4	4	0	75	16	0
1864	5	3	0	101	8	0	1878	3	6	0	68	11	6
1865	4	18	0	94	7	0	1879	3	8	6	64	5	6
1866	4	11	0	91	14	0	1880	4	4	6	69	5	0
1867	4	7	0	82	8	6	1881	4	5	6	68	0	0
1868	4	11	0	78	15	6	1882	3	16	0	73	0	0

TABLE No. 20.

Cost, etc., at Fowey Consols Mine.

Furnished by Mr. Austin Treffy, of Fowey, for 1837.

		£	s.	d.
Quantity of ores raised in 1837 in Fowey Consols Mine	15,710 tons 12 cwts.			
Amount of proceeds for the ores sold, including carriage money paid for the same		89,083	15	2
Total expenses for the year		73,262	16	3
Amount of profit		£15,820	18	11

The expenses are given under the following heads:—

	£	s.	d.
Amount of agency, including purser and clerks	1,361	3	6
„ lord's *dish* or dues	4,886	2	11
„ smithery, carpentry, and sawing	1,701	19	0
„ tutwork	16,347	10	10
„ tribute	18,821	7	11
„ sundry surface labour and sundries	3,392	6	5
„ charges on ores, including carriage and sampling and weighing	5,956	2	0
drawing, filling, and landing	2,229	19	1
parochial rates	292	16	6
paid to sick labourers of both sexes from the sick club*	607	2	0
paid for medical attendance	324	10	5
rent of water and engine charges (exclusive of coals)	2,247	12	3
stores	15,094	3	5
Total expenses †	£73,262	16	3

TABLE No. 21.

Mona Mine, Anglesea.

Year.	Copper Ore	Copper.				Precipitate.	Copper in Precipitate.				Blue Stone.
	Tons.	Tons	cwts.	qrs.	lbs.	Tons.	Tons	cwts.	qrs.	lbs.	Tons.
1855	—	226	8	0	0	—	—				—
1856	—	—				—	—				—
1857	4,507	207	10	0	0	—	—				—
1858	5,026	174	1	0	0	—	—				—
1859	4,688	179	11	3	0	—	—				—
1860	3,[illegible]15	147	10	0	0	—	—				—
1861	2,215	82	16	0	0	888	64	15	3	0	—
1862	2,752	104	14	0	0	842	66	19	3	0	—
1863	2,425	99	14	1	0	664	58	0	3	0	—
1864	2,545	114	0	3	0	459	43	18	2	0	—
1865	2,656	112	12	1	0	391	28	19	2	1	—
1866	3,286	147	17	1	21	876	87	12	1	6	1,221
1867	2,242	91	15	2	0	508	82	4	0	0	765
1868	2,592	144	4	1	10	707	74	0	3	0	1,078
1869	2,324	151	0	0	0	—	—				879
1870	3,500	227	10	0	0	—	—				1,200
1871	3,000	195	0	0	0	—	—				200
1872	2,400	156	0	0	0	—	—				984
1873	1,628	105	16	0	0	297	26	14	2	0	414
1874	150	9	15	0	0	282	25	7	0	0	1,008
1875	600	—				430	Not known.				500
1876	890	—				332	„				50
1877	1,040	38	0	0	0	270	35	15	0	0	—
1878	1,022	37	6	0	0	303	40	0	0	0	360
1879	767	27	10	0	0	202	26	8	0	0	548
1880	2,019	—				Not known.	166	0	0	0	1,569
1881	3,804	152	5	0	0	„	409	0	0	0	1,469
1882	2,611	—				66	—				520

* Each miner in those mines received 30s. per month during illness, and had medical attendance with medicine provided for himself and family, for the support of which a deduction of 1s. 9d. was made upon his monthly earnings.

† The expenses in 1836 were £74,960 5s. 10d.

TABLE No. 22.

RETURN OF COPPER FROM PARYS MOUNTAIN MINE, ANGLESEA.

Year.	Copper Ore.	Copper.				Value of Ore.			Precipitate.	Copper in Precipitate.			
	Tons.	Tons	cwts.	qrs.	lbs.	£	s.	d.	Tons.	Tons	cwts.	qrs.	lbs.
1855	—	412	6	0	0	—			—		—		
1856	—	No return.				—			—		—		
1857	4,864	243	9	0	0	—			—		—		
1858	4,858	227	15	0	0	—			—		—		
1859	3,698	188	1	0	0	—			—	86	0	0	0
1860	4,568	268	11	2	0	—			—		—		
1861	5,260	295	17	2	0	13,620	0	0	399	41	17	0	0
1862	5,398	305	17	0	0	28,421	7	3	359	38	0	0	0
1863	5,027	337	0	0	0	25,876	4	4	327	39	0	0	0
1864	4,565	306	0	0	0	26,159	16	5	296	35	5	1	0
1865	4,468	291	10	0	0	—			269	25	0	0	0
1866	4,084	265	10	0	0	16,437	17	6	271	24	10	[illegible]	0
1867	3,526	150	4	0	0	—			232	22	7	2	0
1868	2,908	189	0	0	0	10,868	6	0	239	21	8	2	5
1869	2,569		—			—			241		—		
1870	2,270	147	11	0	0	—			204	18	8	0	0
1871	2,508	163	0	0	0	—			168	15	2	0	0
1872	2,813	182	1	0	0	—			155	13	19	0	0
1873	1,938	125	19	1	0	3,683	7	11	120	10	16	0	0
1874	3,343	62	10	0	0	4,033	8	11	120	10	15	0	0
1875	2,704		—			6,028	11	6	206		—		
1876	2,323		—			3,893	2	5	187		—		
1877	2,153	42	15	0	0	3,200	14	9	150	19	12	2	0
1878	320	6	7	0	0	704	4	1	151	10	13	0	0
1879	180	4	10	0	0	540	0	0	100	12	13	0	0
1880	960		—			1,657	8	3	—	109	15	3	0
1881	863	34	10	0	0	1,381	2	5	—	119	5	3	0
1882	937		—			1,160	19	4	99		—		

TABLE No. 23.

AN ACCOUNT OF THE FINE COPPER PRODUCED FROM THE MONA AND PARYS MINES, SMELTED AT AMLWCH, BETWEEN THE YEARS 1820 AND 1835.

Years.	Mona Mine.				Parys Mine.				Totals.			
	Tons	cwts.	qrs.	lbs.	Tons	cwts.	qrs.	lbs.	Tons	cwts.	qrs.	lbs.
1820	417	15	2	17	201	19	2	2	619	15	0	19
1821	329	10	3	22	228	17	2	26	558	8	2	20
1822	412	2	3	26	361	19	2	1	774	2	1	27
1823	311	7	1	20	393	13	1	5	705	0	2	25
1824	334	7	1	19	289	10	0	9	623	17	2	0
1825	394	17	0	27	341	13	2	17	736	10	3	16
1826	374	0	3	24	410	12	1	21	784	13	1	17
1827	363	12	2	16	317	6	3	0	680	19	1	16
1828	378	5	2	[illegible]	379	4	2	20	757	10	1	4
1829	394	6	0	25	331	14	1	0	726	0	1	25
1830	526	2	2	25	252	11	2	11	778	14	1	8
1831	580	3	1	12	335	13	0	2	915	16	1	14
1832	513	2	3	1	270	0	0	0	783	2	3	1
1833	328	12	2	8	176	5	0	10	504	17	2	18
1834	375	7	3	5	261	4	0	25	636	12	0	2
1835	333	9	0	19	220	8	2	18	553	17	3	19

TABLE No. 24.

Production of Lead Ore, Lead, and Silver in the United Kingdom in each Year from 1848 to 1871.

(The last ten years being given on page 836.)

Year.	Lead Ore.	Lead.	Silver.	Year.	Lead Ore.	Lead.	Silver.
	Tons.	Tons.	Ounces.		Tons.	Tons.	Ounces.
1848	78,944	53,373	—	1860	88,791	63,225	549,090
1849	86,823	58,715	—	1861	90,666	65,644	570,474
1850	92,958	64,429	—	1862	95,312	69,013	686,123
1851	92,312	65,289	—	1863	91,281	68,221	634,004
1852	91,198	64,961	—	1864	94,463	67,081	641,088
1853	85,843	60,969	496,475	1865	90,452	67,251	724,856
1854	90,554	64,005	562,659	1866	91,051	67,391	636,688
1855	92,251	65,691	561,906	1867	93,432	68,441	805,394
1856	101,997	73,129	614,188	1868	95,236	71,017	841,328
1857	96,820	69,266	532,866	1869	96,866	73,259	831,891
1858	95,855	68,303	569,345	1870	98,176	73,420	784,562
1859	91,353	62,382	578,275	1871	93,965	69,037	761,490

TABLE No. 25.

An Account of the Production of the Lead Mines of Cornwall in each Year since 1845.

Year.	Lead Ore.		Lead.		Silver.
	Tons	cwts.	Tons	cwts.	Ounces.
1845	10,110	0	6,063	0	
1846	8,228	0	4,933	0	
1847	11,574	0	7,304	0	
1848	10,223	0	6,614	0	
1849	10,494	0	6,614	0	
1850	10,325	16	6,773	0	
1851	9,515	4	6,709	3	255,640
1852	8,998	14	6,220	6	250,008
1853	6,680	3	4,690	5	165,670
1854	7,460	1	5,005	10	179,675
1855	8,962	19	5,882	8	211,348
1856	9,973	13	6,597	4	248,436
1857	9,559	16	6,036	7	224,277
1858	9,710	0	5,436	15	223,189
1859	7,842	15	4,985	12	215,964
1860	6,401	3	4,242	15	180,757
1861	6,690	14	4,228	20	173,344
1862	6,030	5	4,119	0	205,662
1863	6,259	14	4,270	15	206,313
1864	5,301	17	3,538	12	192,232
1865	6,546	11	4,296	8	214,659
1866	6,736	10	4,350	11	195,218
1867	8,644	19	6,480	11	314,326
1868	8,415	16	6,310	9	303,033
1869	9,023	3	6,775	0	305,714
1870	8,481	5	6,360	0	292,045
1871	7,565	14	5,672	18	267,234
1872	5,463	10	4,098	15	107,710
1873	3,909	10	2,923	0	129,509
1874	3,119	14	2,337	3	85,304
1875	2,566	10	1,932	2	25,681
1876	2,727	0	2,070	0	37,650
1877	2,166	13	1,673	17	23,035
1878	1,394	14	1,022	2	16,456
1879	725	5	544	18	9,435
1880	753	18	570		11,750
1881	764	17	408		14,396
1882	624	1	454		11,460

TABLE No. 26.

An Account of the Production of the Lead Mines of Durham and Northumberland since the Year 1845.

Year.	Lead Ore. Tons	cwts.	Lead. Tons	cwts.	
1845	17,046	0	11,236	0	
1846	16,9[illegible]	0	11,281	0	
1847	19,18[illegible]	0	12,913	0	
1848	18,815	0	13,178	0	
1849	18,929	18	13,215	6	
1850	21,010	5	15,840	4	
1851	21,163	14	15,488	12	
1852	21,594	3	15,978	11	185,860
1853	19,287	16	15,041	4	131,726
1854	22,329	15	16,669	18	74,700
1855	22,107	18	16,309	19	78,577
1856	24,125	7	17,674	11	75,435
1857	21,580	1	17,073	14	79,924
1858	19,996	2	16,776	7	74,091
1859	19,571	0	14,568	0	78,238
1860	20,200	12	15,186	0	74,222
1861	19,536	15	15,252	17	84,254
1862	21,771	18	16,454	0	78,265
1863	22,774	2	17,205	11	82,854
1864	23,029	19	16,656	12	81,315
1865	21,501	14	16,881	11	78,454
1866	22,555	15	16,974	12	68,887
1867	22,574	2	16,119	6	72,300
1868	23,720	17	17,805	8	77,678
1869	20,793	1	17,177	6	81,447
1870	21,693	0	16,704	10	85,398
1871	21,864	14	16,614	2	66,464
1872	19,106	10	14,399	4	75,776
1873	18,623	11	13,769	9	72,175
1874	18,839	9	15,689	12	47,862
1875	22,304	4	16,525	7	70,336
1876	23,285	9	16,730	3	70,191
1877	25,086	10	18,984	15	74,095
1878	16,869	0	13,190	14	75,686
1879	14,186	10	10,708	2	58,318
1880	18,254	19	15,803	6	44,552
1881	17,467	2	13,089	5	74,630
1882	16,729	1	13,206	6	54,036
					52,04[illegible]

TABLE No. 27.

An Account of the Greenwich Hospital Duty Lead Ore from the Year 1768 to 1881.

Year.	Lead Ore. Bings	cwts.	Lea[d] Tons	Lead Ore.	Lead Ore. Tons	cwts.
1768	2,704	3	1,081		1,509	15
1769	4,246	3	1,698		1,119	11
1770	3,268	5	1,307		1,243	19
1771	3,006	2	1,202		1,372	11
1772	2,867	6	1,[illegible]47		1,243	18
1773	3,146	2	1,258		1,063	12
1774	3,763	4	1,505		1,147	9
1775	4,840	4	1,936		1,122	19
1776	3,715	4	1,486		1,363	7
1777	3,263	2	1,305		1,641	9
1778	3,927	2	1,570		2,008	12
1779	3,792	2	1,516		1,382	2
1780	4,235	1	1,694		1,480	18
1781	3,373	6	1,349		1,637	16
1782	3,007	6	1,203		1,534	14
1783	3,732	2	1,49[illegible]		974	4

TABLE No. 27 (*continued*).

Year.	Lead Ore.		Lead Ore.		Year.	Lead Ore.		Lead Ore.	
	Bings*	cwts.	Tons	cwts.		Bings	cwts.	Tons	cwts.
1800	2,526	1	1,010	9	1830	3,505	6	1,402	6
1801	2,511	6	1,004	14	1831	3,003	3	1,201	7
1802	2,917	7	1,167	3	1832	2,630	2	1,052	2
1803	3,097	5	1,239	1	1833	2,316	2	926	10
1804	3,365	4	1,346	4	1834	2,106	3	842	11
1805	2,944	3	1,177	15	1835	2,283	1	913	5
1806	2,414	5	965	17	1836	2,154	5	861	17
1807	2,484	5	993	17	1837	2,233	3	893	7
1808	3,202	5	1,281	1	1838	2,322	5	929	1
1809	2,867	5	1,147	1	1839	2,063	0	825	4
1810	1,987	6	795	2	1840	2,004	5	801	17
1811	2,210	6	884	6	1841	2,417	5	967	1
1812	2,129	0	851	12	1842	2,462	5	985	0
1813	2,618	3	1,047	17	1843	2,837	1	1,134	17
1814	2,294	1	917	13	1844	2,501	7	1,024	15
1815	2,287	6	915	2	1845	2,441	7	976	15
1816	2,120	1	849	13	Returns not obtainable in the same form until 1871.				
1817	2,743	3	1,097	7					
1818	3,558	3	1,423	7					
1819	3,563	5	1,425	9	1871			1,631	7
1820	4,349	2	1,739	14	1872			1,444	2
1821	4,854	5	1,941	17	1873			1,214	6
1822	4,795	4	1,918	4	1874			926	2
1823	4,768	2	1,907	6	1875			1,004	13
1824	5,486	0	2,194	8	1876	Bings not returned.		1,406	7
1825	5,757	7	2,303	3	1877			1,680	8
1826	4,858	6	1,943	10	1878			1,636	8
1827	4,842	5	1,937	1	1879			1,433	0
1828	4,399	5	1,759	17	1880			1,409	0
1829	4,156	6	1,662	14	1881			1,445	6

TABLE No. 28.

AN ACCOUNT OF THE LEAD ORE, LEAD, AND SILVER PRODUCED FROM THE ALLANDALE EAST AND WEST AND WEARDALE MINES FROM 1845 TO 1881.

Year.	Lead Ore.	Lead.	Silver.	Year.	Lead Ore.	Lead.	Silver.
	Tons.	Tons.	Ounces.		Tons.	Tons.	Ounces.
1845	12,200	8,130	—	1864	12,006	8,608	42,949
1846	12,000	8,000	—	1865	10,301	8,505	45,464
1847	13,600	[illegible],300	—	1866	9,712	8,197	42,126
1848	13,230	9,080	—	1867	11,310	7,771	42,287
1849	13,362	9,162	—	1868	12,360	9,650	44,876
1850	13,380	9,804	—	1869	10,402	9,407	52,486
1851	13,560	9,977	—	1870	10,259	8,225	37,988
1852	13,840	9,313	—	1871	10,507	8,021	45,988
1853	11,916	19,904	50,700	1872	8,895	6,760	37,180
1854	12,220	9,200	49,000	1873	8,370	6,095	19,208
1855	12,007	9,031	51,825	1874	7,486	7,152	41,486
1856	11,900	9,437	56,662	1875	9,052	6,322	30,847
1857	10,674	8,974	53,603	1876	8,260	5,287	23,990
1858	8,801†	8,448‡	47,575	1877	9,821	7,367	30,896
1859	9,473	7,659	42,758	1878	4,267	3,594	21,157
1860	8,950	6,925	39,240	1879	1,624	1,218	6,090
1861	9,700	8,120	46,080	1880	3,910	5,079§	37,669
1862	10,714	8,300	45,840	1881	3,273	2,454	16,968
1863	10,728	8,482	44,613				

* The Bing is 8 cwts.

† Ore raised in the year ending June, 1858. ‡ Lead made in the year ending December, 1858.

§ A considerable quantity of this was obtained from lead ore raised in 1879.

TABLE No. 29.

An Account of the Production of the Lead Mines of Cardiganshire in each Year since 1845.

Year.	Lead Ore.		Lead.		Silver.
	Tons	cwts.	Tons	cwts.	Ounces.
1845	5,726	0	3,716	0	—
1846	5,718	15	3,712	10	—
1847	4,899	0	3,176	10	—
1848	4,882	0	3,180	0	—
1849	5,988	15	3,895	0	—
1850	6,687	15	4,768	12	—
1851	7,182	18	5,809	7	87,135
1852	7,370	10	5,305	8	79,575
1853	6,552	15	4,909	19	30,477
1854	7,034	0	4,948	15	33,418
1855	7,043	3	5,014	8	28,079
1856	8,560	1	6,191	10	38,751
1857	7,573	9	5,509	12	37,097
1858	7,086	12	5,440	3	41,100
1859	7,466	14	5,569	9	37,787
1860	7,355	1	4,952	15	44,807
1861	7,755	5	5,886	2	54,989
1862	8,299	11	5,443	2	62,678
1863	7,131	17	5,661	12	58,846
1864	7,464	3	4,452	14	46,486
1865	7,835	6	5,877	1	54,617
1866	7,700	1	5,799	17	61,455
1867	7,838	18	5,866	7	63,113
1868	7,230	14	5,414	10	67,502
1869	8,180	4	6,216	11	66,145
1870	7,307	5	5,532	10	56,553
1871	7,552	19	4,692	16	46,980
1872	6,764	3	4,998	13	41,690
1873	5,372	19	4,056	19	39,869
1874	5,423	4	4,075	11	41,047
1875	5,835	0	4,401	17	46,624
1876	5,961	16	4,468	19	45,418
1877	5,849	18	4,644	6	47,284
1878	6,801	8	5,143	5	49,028
1879	5,079	12	3,990	6	42,770
1880	6,404	14	5,016	15	49,445
1881	4,598	3	3,381	11	28,[illegible]65
1882	4,036	13	3,157	10	29,626

TABLE No. 30.

Account of the Production of the Lead Mines of the Isle of M in each Year since 1845.

Year.	Lead Ore.		Lead.		Silver.
	Tons	cwts.	Tons	cwts.	Ounces.
1845	2,259	0	1,523	0	—
1846	2,316	0	1,663	0	—
1847	2,575	0	1,699	0	—
1848	2,521	0	1,665	0	—
1849	2,326	10	1,535	1	—
1850	2,175	0	1,218	19	—
1851	2,500	0	1,402	10	33,980
1852	2,415	0	1,835	5	36,700
1853	2,460	0	1,829	0	47,105
1854	2,800	0	2,137	0	52,262
1855	3,573	5	2,725	0	51,597
1856	3,217	18	2,450	18	60,382
1857	2,656	0	2,027	15	48,016
1858	2,457	0	1,880	19	46,985
1859	2,464	0	1,880	10	56,974
1860	2,810	0	2,091	9	60,170

TABLE No. 30 (*continued*).

Year.	Lead Ore.		Lead.		Silver.
	Tons	cwts.	Tons	cwts.	Ounces.
1861	2,717	19	2,403	8	67,282
1862	2,508	12	1,861	0	70,592
1863	2,561	11	2,012	0	74,289
1864	3,118	2	2,350	5	125,020
1865	3,142	0	2,321	0	123,221
1866	3,494	8	2,571	11	147,516
1867	3,799	0	2,834	0	165,170
1868	4,290	0	3,089	5	178,718
1869	4,302	0	3,117	15	172,839
1870	4,604	10	3,266	9	172,528
1871	4,645	7	3,334	12	176,331
1872	3,529	0	2,639	2	145,433
1873	4,371	12	3,131	9	163,058
1874	4,204	14	3,185	3	161,612
1875	4,429	0	3,158	10	183,524
1876	4,353	1	3,086	1	170,105
1877	4,464	3	3,342	12	186,019
1878	3,920	13	2,995	9	110,496
1879	4,358	12	3,267	0	100,476
1880	5,118	18	3,886	5	59,667
1881	5,675	0	4,183	12	84,865
1882	5,494	0	4,267	17	129,769

TABLE No. 31.

AN ACCOUNT OF THE PRODUCTION OF THE LEAD MINES OF SCOTLAND IN EACH YEAR SINCE 1845.

Year.	Lead Ore.		Lead.		Silver.
	Tons	cwts.	Tons	cwts.	Ounces.
1845	1,173	0	901	0	—
1846	1,161	0	942	0	—
1847	1,159	0	822	10	—
1848	2,588	0	1,736	0	—
1849	1,421	15	957	3	—
1850	3,117	5	2,124	5	—
1851	3,113	0	2,140	0	6,576
1852	3,499	0	2,381	7	19,048
1853	2,799	7	1,919	4	5,860
1854	1,753	11	1,278	19	5,426
1855	1,587	0	1,159	12	4,947
1856	1,931	0	1,416	12	5,289
1857	1,890	9	1,351	4	4,206
1858	2,290	10	1,585	11	4,882
1859	1,[illegible]2	9	1,347	9	4,022
1860	1,[illegible]73	15	1,358	15	3,140
1861	1,761	1	1,229	16	4,133
1862	1,767	5	1,262	6	6,190
1863	1,455	19	1,086	5	6,006
1864	2,072	16	1,591	8	7,843
1865	2,363	17	1,774	17	8,704
1866	2,423	18	1,730	10	8,704
1867	2,954	2	2,107	19	11,428
1868	2,436	13	1,811	13	8,201
1869	3,181	1	2,271	16	7,797
1870	3,353	15	2,390	2	5,680
1871	3,392	19	2,449	4	5,285
1872	3,605	5	2,331	7	5,900
1873	3,207	1	2,125	0	10,720
1874	2,931	1	2,073	0	11,317
1875	4,109	14	3,078	10	13,303
1876	3,910	4	2,936	6	12,214
1877	2,706	16	2,105	2	11,306
1878	4,236	0	2,743	0	14,320
1879	3,702	11	2,770	15	12,075
1880	3,956	13	2,848	1	14,379
1881	3,806	17	2,839	15	13,412
1882	4,401	1	3,376	12	27,435

TABLE No. 32.

An Account of the Production of the Lead Mines of Ireland in each Year since 1845.

Year.	Lead Ore.		Lead.		Silver.
	Tons	cwts.	Tons	cwts.	Ounces.
1845	1,944	0	855	10	—
1846	1,641	0	811	0	—
1847	2,251	0	1,380	0	—
1848	1,912	0	1,188	0	—
1849	2,739	0	1,653	14	—
1850	2,895	6	1,746	1	—
1851	3,222	16	1,829	7	13,810
1852	4,493	14	3,222	18	32,220
1853	3,309	10	2,452	7	17,664
1854	3,069	15	2,210	10	18,096
1855	2,405	15	1,732	0	7,252
1856	2,483	17	1,602	5	3,700
1857	2,298	19	1,407	3	3,071
1858	2,603	10	1,704	20	14,361
1859	2,477	10	1,613	15	13,998
1860	2,433	15	1,563	20	14,365
1861	2,403	0	1,592	12	12,398
1862	2,643	20	1,763	2	12,481
1863	2,412	10	1,608	13	13,165
1864	2,201	20	1,441	7	15,534
1865	1,777	12	1,334	4	16,830
1866	1,822	16	1,224	5	15,039
1867	1,882	12	1,308	0	12,140
1868	2,089	0	1,562	10	14,372
1869	1,979	0	1,478	19	5,480
1870	1,415	10	1,061	12	2,815
1871	1,115	0	834	15	—
1872	962	0	726	5	1,040
1873	1,180	0	885	0	4,420
1874	1,752	14	1,313	12	6,555
1875	1,850	8	1,387	18	6,935
1876	1,825	4	1,368	18	6,840
1877	1,655	18	1,241	0	6,205
1878	1,704	1	1,263	10	5,650
1879	1,272	9	911	0	4,000
1880	1,244	19	931	15	3,360
1881	848	16	636	2	4,932
1882	992	4	733	13	4,988

TABLE No. 33.

Prices of Lead at Grassington paid at the Smelting House for Duty Lead.

Year.	Lead. Price per Ton.			Year.	Lead. Price per Ton.			Year.	Lead. Price per Ton.		
	£	s.	d.		£	s.	d.		£	s.	d.
1780	11	7	6	1802	24	16	6	1823	22	5	0
1781	12	18	6	1803	27	15	6	1824	21	0	0
1782	16	13	0	1804	28	0	0	1825	25	6	0
1783	19	12	0	1805	27	11	0	1826	19	0	0
1784	16	8	0	1806	35	12	6	1827	18	7	9
1785	16	1	0	1807	30	3	6	1828	17	9	0
1786	16	2	6	1808	30	1	0	1829	14	5	0
1787	21	4	0	1809	31	3	0	1830	12	3	6
1788	21	10	0	1810	28	16	0	1831	12	4	0
1789	19	17	6	1811	24	0	6	1832	11	13	4
1790	16	1	6	1812	23	3	6	1833	12	12	0
1791	18	2	6	1813	25	14	0	1834	16	11	8
1792	19	8	0	1814	26	11	0	1835	17	9	6
1793	19	3	0	1815	20	16	0	1836	24	2	10
1794	14	10	0	1816	16	5	0	1837	19	3	6
1795	16	15	0	1817	18	5	0	1838	18	9	9
1796	18	6	0	1818	27	5	6	1839	17	2	10
1797	16	17	0	1819	22	11	0	1840	18	6	4
1798	15	7	6	1820	21	10	6	1841	18	14	8
1799	16	9	6	1821	22	10	0	1842	16	10	0
1800	19	16	0	1822	22	7	0	1843	16	5	0
1801	22	8	6								

TABLE No. 34.

Prices of English Lead per Fodder,* from the Year 1783 to 1828.

Year.	English Lead, per Fodder. £	s.	d.	Year.	English Lead, per Fodder. £	s.	d.
1783	18	14	2	1806	39	18	4
1784	17	10	0	1807	35	0	10
1785	17	18	3	1808	31	18	0
1786	17	15	10	1809	39	15	0
1787	20	4	7	1810	36	18	4
1788	23	2	1	1811	30	14	2
1789	21	8	9	1812	29	10	0
1790	18	16	0	1813	29	16	8
1791	19	13	4	1814	31	11	8
1792	20	15	0	1815	26	9	0
1793	20	5	10	1816	20	18	4
1794	19	0	0	1817	19	8	4
1795	18	3	1	1818	25	10	0
1796	21	6	3	1819	24	15	10
1797	19	10	0	1820	23	10	0
1798	19	3	4	1821	21	2	6
1799	21	3	4	1822	22	13	4
1800	21	18	4	1823	23	10	0
1801	25	18	4	1824	23	5	0
1802	30	10	0	1825	27	15	0
1803	33	5	0	1826	22	2	6
1804	33	0	0	1827	20	11	8
1805	37	16	8	1828	19	6	8

TABLE No. 35.

An Account of the Zinc Ore and Metallic Zinc obtained from the Mines of the United Kingdom in each Year from 1856 to 1882.

Year.	Zinc Ore. Tons	cwts.	Metallic Zinc (Spelter). Tons	cwts.	Year.	Zinc Ore. Tons	cwts.	Metallic Zinc (Spelter). Tons	cwts.
1856	9,003	0	—		1869	15,532	0	4,500	0
1857	9,289	0	—		1870	13,586	0	3,936	0
1858	11,556	2	3,466	0	1871	17,736	10	4,966	0
1859	13,039	0	3,697	0	1872	18,542	0	5,191	0
1860	15,552	14	4,357	0	1873	15,969	1	4,471	0
1861	15,770	0	4,415	0	1874	16,829	16	4,470	0
1862	7,497	13	2,151	0	1875	23,978	0	6,713	0
1863	13,699	2	3,835	0	1876	23,613	8	6,641	0
1864	15,047	6	4,040	0	1877	24,405	16	6,833	10
1865	17,842	15	4,460	0	1878	25,438	2	6,309	0
1866	12,769	0	3,192	10	1879	22,200	0	5,554	0
1867	13,489	8	3,750	0	1880	27,547	15	7,162	0
1868	12,781	13	3,713	0	1881	36,527	7	14,947	5
					1882	32,479	14	16,118	9

* "A Fodder of Lead at the Mines contains twenty-two hundred and a-half weight, though in London but twenty hundred weight." ("Collection of *Scarce* and Valuable Treatises upon Metals, Mines, and Minerals." Printed for J. Hodge, at the Looking Glass, on London Bridge, in 1740.)

TABLE No. 36.

Average Prices of Zinc Ore and Metallic Zinc in each Year since 1858.

Year.	Zinc Ore.	Metallic Zinc (Spelter).	Year.	Zinc Ore.	Metallic Zinc (Spelter).
	£ s. d.	£ s. d.		£ s. d.	£ s. d.
1858	—	25 5 0	1870	3 9 0	18 16 6
1859	3 0 0	21 0 3	1871	3 15 0	18 11 6
1860	2 10 0	20 11 0	1872	4 8 0	22 15 0
1861	2 0 0	17 18 4	1873	3 15 0	26 15 0
1862	2 2 6	18 6 6	1874	3 7 6	23 6 0
1863	2 7 0	18 2 0	1875	4 2 3	24 5 0
1864	3 0 6	22 2 6	1876	4 12 0	24 3 0
1865	2 18 0	20 12 0	1877	3 17 4	21 15 0
1866	3 6 9	21 18 0	1878	3 7 8	19 10 0
1867	3 1 3	21 6 0	1879	3 9 3	17 5 0
1868	3 1 4	20 6 4	1880	4 1 0	19 4 6
1869	3 3 6	20 10 8	1881	3 6 8	16 18 0

TABLE No. 37.

Imports and Exports of Zinc from 1823 to 1858.

Duty per Ton.	Year.	Imports.	Exports to India.	Total Exports.	Home used.	Highest and Lowest Prices.	Remarks.
		Tons.	Tons.	Tons.	Tons.	£ s. £ s.	
	1823	5,400	4,536	4,700	—	22 0 to 23 0	Beida Co. speculation.
£28 10s.	1824	9,199	7,185	8,068	24	24 0 ,, 23 0	
	1825	5,556	4,835	6,112	171	22 10 ,, 41 10	
14s.	1826	4,839	7,374	8,330	22	28 0 ,, 15 10	All exported to India for seven years, with low prices there (from 14 to 5¼ rupees), while our market was similarly affected downwards from the glut of that importation.
12s.	1827	5,999	5,535	6,929	290	16 10 ,, 14 0	
	1828	4,566	4,806	4,943	536	14 10 ,, 11 13	
	1829	4,230	3,505	3,964	684	12 0 ,, 9 9/6	
10s.	1830	4,422	3,385	3,479	843	9 10 ,, 11 0	
	1831	3,821	2,896	3,134	941	11 5 ,, 9 5	
	1832	3,140	2,044	2,995	1,093	10 10 ,, 11 0	
	1833	2,800	1,225	1,883	1,355	10 10 ,, 12 0	Gradual revival for 4 years.
	1834	2,100	882	1,419	1,756	12 0 ,, 14 10	
	1835	6,500	2,497	3,943	2,205	15 0 ,, 17 0	
	1836	8,600	1,490	6,269	2,184	16 10 ,, 23 10	
	1837	4,380	1,811	3,200	2,335	18 10 ,, 12 0	Commercial panic in summer.
	1838	6,265	528	1,858	3,596	15 10 ,, 20 0	Natural level for 3 years.
	1839	8,910	1,538	3,391	4,560	18 5 ,, 21 15	
	1840	4,965	2,687	4,091	4,181	20 0 ,, 23 10	
	1841	6,509	990	1,400	3,665	23 10 ,, 10 0	Pottinger's speculation and sales the following year.
	1842	5,500	1,584	1,900	2,641	36 0 ,, 14 0	
1s.	1843	10,173	3,459	6,445	4,125	23 0 ,, 22 0	Steady at natural level.
	1844	10,393	5,826	5,925	5,388	22 5 ,, 10 8	
	1845	12,903	2,969	3,084	7,459	22 5 ,, 15 0	
	1846	11,434	4,875	4,967	8,450	22 0 ,, 19 10	
	1847	12,729	3,301	3,631	11,794	22 0 ,, 19 10	
	1848	13,525	2,831	3,773	9,344	19 15 ,, 13 0	French Revolution.
	1849	15,915	3,927	5,397	8,726	15 0 ,, 16 5	Late speculative position and present state of market.
	1850	18,626	3,121	4,537	11,262	15 0 ,, 17 10	
	1851	22,986	2,417	5,553	—	16 5 ,, 15 0	
Free	1852 (May 1)	18,505	456	7,252	—	14 5 ,, 19 15	
	1853	23,418	925	12,643	—	19 10 ,, 24 5	
	1854	19,583	2,766	8,359	—	20 0 ,, 25 10	
	1855	17,852	2,741	5,156	—	22 5 ,, 25 0	
	1856	18,213	2,588	5,428	—	23 15 ,, 28 15	
	1857	18,001	2,269	3,504	—	23 10 ,, 31 10	
	1858	23,725	5,053	7,731	—	22 15 ,, 27 10	

TABLE 38.

PRODUCTION OF MANGANESE FROM 1872 TO 1881.

Name of Mines.	1872.	1873.	1874.	1875.	1876.	1877.	1878.	1879.	1880.	1881.
	Tons cwts. qrs.	Tons cwts qrs.	Tons cwts. qrs.	Tons cwts. qrs.	Tons cwts. qrs.	Tons cwts. qrs.	Tons cwts. qrs.	Tons cwts. qrs.	Tons cwts. qrs.	Tons cwts. qrs.
Alliford	40 0 0	—	—	—	—	—	—	—	—	—
Chillaton and Hogstor .	7,681 0 0	8,254 0 0	5,054 10 0	2,754 7 1	2,430 0 0	2,159 0 0	1,000 0 0	400 0 0	800 0 0	1,224 0 0
Bamfylde	—	59 0 0	—	36 0 0	—	—	—	—	—	—
Narracolt	—	153 0 0	115 0 0	68 0 0	—	—	—	—	—	—
Newton St. Cyrus . .	—	191 8 0	304 0 6	109 0 6	129 0 0	287 0 0	200 0 0	40 0 0	—	—
Shirwill and Braton . .	—	17 0 0	—	—	—	—	—	—	—	—
Cot Quarry, *Barnstable* .	—	—	50 0 0	—	—	—	—	—	—	—
Devonshire.	—	—	40 0 0	37 0 0	—	—	—	—	—	—
Edgcombe	—	—	20 0 0	—	10 0 0	—	—	—	—	—
Longstone	—	—	50 0 0	—	—	—	—	—	—	—
Rostidgon and Deep Level	—	—	60 0 0	—	—	—	—	—	—	—
Ruthers	—	—	24 11 0	25 0 0	—	—	—	—	722 12 0	300 0 0
St. Stephen's	—	—	10 0 0	—	—	37 0 0	60 0 0	45 0 0	—	—
Ludcott and West Down .	—	—	—	16 0 0	—	—	—	42 0 0	70 0 0	150 0 0
Riley, *Ilsington* . . .	—	—	—	118 0 0	—	—	—	—	—	—
Coad's Green	—	—	—	—	21 0 0	—	—	—	—	—
Bawden Common . . .	—	—	—	—	76 0 0	19 0 0	—	—	—	—
Perran New Iron Mine .	—	—	—	—	—	—	49 4 0	—	—	—
Greystone Wood . . .	—	—	—	—	—	—	35 0 0	20 0 0	40 0 0	—
Monkstone	—	—	—	—	—	—	—	57 0 0	720 0 0	—
Stannacombe	—	—	—	—	—	—	—	—	40 0 0	—

GLOSSARY OF TERMS

EMPLOYED IN, OR RELATING TO, METALLIFEROUS MINING IN THE BRITISH ISLES.

ADIT. From the Latin word *Aditus*, an entry; passage or approach to the mine.

ATTAL, or ATTLE. Waste; the débris formed by the dressing of ores. The waste of the mine.

ATTAL-SARSEN, or SARACEN. The waste or remains of the stranger; sometimes called "Jews' leavings."

BACK. The roof of a level.

BACK OF A LODE. The portion between a level driven on the lode and the surface.

BANGERTS. A coarse sort of stopping used to hold up the earth.

BAR. A grip or twitch in a vein or pipe, "striking it dead" (*Hooson*).

BARMASTER. An officer in Derbyshire kept at the charge of the lord; "he is servant to both lord and miner—to the lord in gathering his duty or dues, and to the miner to measure his ore, seeing equal and just measure, laying out mineral ways," &c. &c.

BARMOTE COURT. A court held in Derbyshire twice in the year only, established by a decree in Edward III.'s time.

BATCH. A batch of tin signifies a heap, or "parcel of tin."

BELLAND. A distemper lead-miners are subject to; a kind of lead-poisoning.

BELLY. A swelling mass of ore in the lode.

BEU or BEUHEYL. A "living stream"; the productive portion of a tin stream.

BING ORE. The largest and best kind of lead ore.

BINGSTEAD. The place where bing ore is dressed.

BLACK TIN. Oxide of tin; Cassiterite. Tin ore triturated, dressed, and rendered clean for smelting.

BLANCH. A piece of ore found isolated in the hard rock.

BOKE. A small run in pipes, found connecting the ore, running through the vein.

BOLES. In Derbyshire, old lead works. Places on high ground and exposed to the wind, where smelting has been carried on.

BOOSE. That part of the vein which affords round lead ore.

BOOTIT. A term used by Derbyshire miners for loss—"last reckoning I' *bootit* it thirty."

BORER. A piece of round iron about 20 inches long, with a steel point, which is driven into the rock to make holes for the purpose of blasting.

BOUT. A word used in measuring lead ore; a long *bout* is 24 dishes, a short *bout* is 12 dishes.

BRACE. A platform on which the miners stand to work the tackle.

BRASSIL. A hard substance resembling brass in colour; often applied to pyritic ores.

BRAZEN DISH. The gauge, or standard, used in the Low Peak, Derbyshire, made of brass, chained to a certain place. The miners measure their lead ore in this dish.

BREAKING. A method of breaking poor or dredge ore by hand with flat irons, called breaking hammers.

BROOD. Any heterogeneous mixture with tin or copper ore, as mundic (iron pyrites) or black-jack (blende).

BUDDLE. A long horizontal box into which the pulverised tin-stuff is deposited by a continuous stream of water, after having passed over the upper part. A circular, and sometimes inclined, table upon which ores are more or less freed from vein-stuff or waste.

BUDDLE WORK. Dressed, and partly-dressed ore obtained from the buddle.

BUNNINGS. In Derbyshire, stages of wood across the mine; a roofing.

BURK. A hard knot or lump in the vein.

CALLEN, or KALLEN. A term used in St. Just to signify iron, especially where a lode is abundant in a soft iron ochre—as *Huel Boys Callen*, *Grouse Callen Lode*.

CANNY. Many of our lodes contain beds of carbonate of lime and fluor-spar, *alias* "cann'" the lode is then called canny.

CARBONA. *A treasure-house.* A large flat deposit of tin ore. See p. 496.

CASED TIN. That which is reframed by a gentle current of water, and prevented from running off the frame or table.

Castaways. Sterile veinstone.

Cavers. People who go from mine to mine picking up small bits of lead ore.

Clay Iron. An iron tool used for driving through clay, which in some very hollow ground it is necessary to use, to facilitate the blasting of the rock; the charge being in that case put into the hole when the clay-iron is withdrawn.

Coarse. When a lode, or the stuff from it, is not rich, the metal being only thinly disseminated throughout, it is called a "coose lode," or "coose stuff." Dradgy has the same meaning.

Cobbed Ore. Ore broken from the veinstone by means of a small hammer.

Côe. A small cabin built over the shaft, of clods or boards, to keep the shaft dry.

Cöffer. *Cöfar*, *Kopher*, a chest in which the stuff is pulverised by means of stamp heads.

Coffin, or Koffens. This applies to old workings at the surface, and what would be a *gunnis* underground is at surface called a coffin. It applies to "old workings" on the course of lodes, which are generally the result of the ancients having carried away the soft ground, viz. the gozzany, flukany, or slovany parts of the lode, easily broken down, and then dressed by them for the tin found in it.

Cope, or Cope Money. In Derbyshire, the price per ton of lead ore.

Coper. A Derbyshire miner.

Costeaning (Cothas-Stean). Fallen or dropped tin. Searching for tinstones.

Costening Pits. Pits dug in search for tin.

Country, The. The rocks in which the mineral vein lies.

Creaze. The "work" or tin in the middle part of the buddle, which is divided into the head or fore part of the buddle, the *creaze* or middle, and the tail or last, sometimes called the *hind creaze*.

Crop. Ore, or tin, of the first quality, after it is dressed or cleansed for smelting.

Cross Cöurses. Veins not metalliferous, usually at right angles to the lode.

Cross Cuts. Horizontal galleries not driven in the productive vein.

Dacker of Wind. Foul air in a mine. "Warm and close foggy weather is bad, and when pease was in blossom then was the worst time for wind in the mines of all the year" (*Hooson*).

Damp. As fire-damp, choke-damp, ground-damp, &c.—Light carburetted hydrogen, carbonic acid, or other gases injurious to life.

Day. The light seen at the top of a shaft.

Dead. A place where there is no ore.

Dillueing. A method of washing, or finishing the dressing of tin, copper, or lead ore on very fine hair sieves.

Dilluer. A horse-hair sieve.

Dippas. Little pits in a mine.

Douk or Douke. Probably derived from the Saxon *deagan*, to knead or mix with water. A soft substance found in veins.

Dradge. Pulverised refuse.

Dradgy. A dradgy lode signified a coarse lode, or rather a lode or stone through which the ore is so thinly disseminated as to be scarcely worth the expense of dressing. Such lode, ore-stuff, or stone is called "dradgy."

Dresser. Any person who superintends the boys and girls on the dressing-floors.

Drifts Opening. Horizontal openings or adits in veins.

Drivings. All excavations horizontally.

Druses. Hollow cavities in the lode.

Equivalents. Grains of ore or vein-stuff of varying diameters and density, which fall through water at an equal rate of velocity.

Estovers. "It has been held that when the commoners have a customary right to dig gravel, or take *Estovers*, the lord had no right to approve or inclose." ("Law of Mines and Minerals," by Wm. Bainbridge.)

Eye of a Shaft. The very beginning of a pit.

Faddom. A fathom, 6 feet, commonly used as a measure by miners.

Famp (Cumberland). Decomposed Limestone, or in other districts a silicious bed composed of very fine particles.

Fange. A place left, as the miners drive along the drift, to carry the air freely onward.

Fausteds. The waste left in the sieve separated from the last of the ore.

Fiery Drake, or Burning Drake. A meteoric appearance, supposed to indicate the place of a lead lode—a superstition nearly exploded.

Fine Raggings. Pieces of ore deposited at the bottom of a sieve.

Flats. Decomposed beds of Limestone. Flat or Flot. *Hooson*, a Derbyshire miner, in 1747, describes them thus:—"It is neither vein-pipe, rake, nor scrin, but

a place that hath both length, breadth, and thickness, but all uncertain."

FLUKAN. Generally a *soft greasy* substance, sometimes running on the lode and sometimes in, and under the lode. When it runs *in* the lode it is called the pith (pronounced *peath*) of the lode.

FOACH. A narrow level is called a "Foaching little level." When a miner has not obtained what he considers a full price for his contract he would be likely to say, "'Twill do 'pon a foach," viz. it will do on a push. Foach is nearly synonymous with another old Cornish word, "Pock," or "Pokkin," to push.

FODDER. A *fother* or *futher*, (Teut.) *Fuder*, a burthen, and this from *futixen*, to carry, and from the Latin *vehere quod*, as much as can be carried in one cart ("Doomsday, Mines in Derbyshire"). At the time of the great survey, 20th William the Conqueror, in "Doomsday," under Derbyshire, and in the parishes in the Peak, among the rents is mentioned the rent of lead, and the return is thus: "*Et quintæ plaustras plumbi, et de quinquaginta tatulis.*" The five plaustras are five cart-loads, and the other are fifty sheets of lead. Then the duty was paid and delivered in measure by the load, and the load is still preserved in the ore. In ancient times the fodder was determined by measure; latterly it is estimated by weight, and the fodder or wey of lead is said to contain eight pigs or sixteen pieces, and every pig, or two pieces, 23½ or 24 stone. A fodder of lead in London is 2,184 lbs. weight; in Bristol, 2,240 lbs. weight: in Hull, 2,340 lbs. weight; in Newcastle-upon-Tyne, 2,352 lbs. weight; in Chester and Liverpool, 2,400 lbs. weight; in Stockton, 2,464 lbs. weight; in Derby, 2,520 lbs. weight.

FOUNDER. The first shaft sunk upon a vein. From this the miner possesses, and lays out his ground.

FRAME OR RACK. A table composed of boards slightly inclined, over which runs a small stream of water to wash off waste from slime tin.

FREEING A MEAR. The first dish of ore is given to the lord of the mine, which frees the miner.

FUSE. A hollow tube for ignition made of a fine case of yarn, filled with gunpowder and pitched on the outside to prevent wet reaching the core, viz. the gunpowder.

GAD. A steel wedge for separating the rock.

GANGUE. Mineral associated with ore.

GARDE. Small pryany matter, coarse sand separated in dressing tin.

GHURR, THURR, or "THE MOTHER OF METALS." The matter or substance which in time is supposed *to ripen*, and become real ore. Glauber the alchemist (from whom we get Glauber's salts (sulphate of soda) tells us "that in Germany the miners know when the ores are not grown to perfection, and usually say they are come too soon; and shut up the mine again for some years till it is ripened and grown to perfection."

GINGING (Derbyshire). Timbering a shaft.

GIRDLE BEDS. Thin beds of a hard and compact kind of Limestone.

GOZZAN. Soft, ferruginous part of the lode, generally found near the surface, and, when of favourable appearance, highly valued by the miner, as ominous of good results.

GRAIN TIN. Oxide of tin in the form of grains or pebbles.

GRATE (STAMP). An iron or copper plate thickly punched with small holes.

GRIDDLE. A large wire sieve for sifting ore.

GRIZZLEY. See *Slide*.

GROOVE. The mine or work that a man is employed in—"He is gone to the groove." Miners in Derbyshire were commonly called "groovers."

GROUP OF GRAINS. Grains of ore-stuff of different dimensions which may exist between two specified dimensions of grains.

GRUFFS. Names given to old mines on the Mendip Hills.

GRUMMET. Rope laid into a ring. Rope grummets are used as wads in firing shots.

GUIDES (St. Just). Cross veins.

GUNNIS. This signifies the horizontal excavation on a lode. The common size adopted for a level is about 7 feet by 3 feet, but from the peculiar nature of the lode it is found an advantage to the miner to break it down much wider and higher than that. The miner would then say, "We are foased (forced) to work thicky (that) end with a laerge gunniz."

HALVANS. Sand or waste resulting from the dressing of ore. These may be considered as the general leavings of the mine, and consist of small particles of ore in the burrows, precipitates into the

dressing-floors, &c. Halvans, after being sett on tribute to those tributers called "halvaners" by the adventurers, are frequently resett by the lords (or their agents), after the workings have been abandoned.

HAZLE. A Saxon word, denoting a Sandstone that is mined with difficulty.

HEADS. The upper or concentrated portion of ore lodged on a buddle or frame.

HEAVE. When the lode is lost in the end of the level, by a cross course, flukan, gozzan, or other cause, the lode is said to be "hove" or heaved.

HILLOCK. A heap of sterile vein-stuff or stone.

HORSE IN THE LODE. A dead or worthless part in the lode; generally composed of fragments of the strata through which the lode passes, which invariably divides the lode.

HOUSE OF WATER. An abandoned mine filled with water—therefore dangerous to all adjoining mines.

HUEL. The old and correct Cornish spelling of Wheal, a mine.

HULKING. Hulking the lode means taking down (removing) the soft part of the lode previous to taking away the harder parts thereof, which is done with considerably less trouble after the miner has "gore in" with his hulk. "I've known miners hulk their lode the whole extent of their 'stent' (bargain), viz. several fathoms, before breaking any of the metalliferous part of the lode down."

HUSHING. Allowing a stream of water to flow over and carry away the soil, so that a lead lode may be exposed if it exists.

HUTTRILL. Any hard pannel in a vein.

JAUM. A joint of clay running across a vein.

JIGGER WORK. Dressed and partly-dressed ore obtained from jiggers.

JIGGING. This applies to the *dradgy* stuff which, being first reduced to several sizes smaller than backed stuff (chiefly by a crusher), is washed in sieves suspended in water, the action of *jigging* (viz. *shaking*) having caused the metallic (consequently the heaviest) particles to precipitate, the skimpings, are scraped off and thrown away, the ore being taken care of. A method of dressing small ore by a pulsating motion, imparted either to a sieve or to stuff lodged in a sieve.

JOINT. A parting in the rock, rider, or ore, or any other substance in the mines.

JOUPH-HOLES (Derbyshire). Hollows in the vein.

KAPLE or CAPLE. The Caples of the lode imply the walls and the effects of the walls of the lode in the general strata. It is not unfrequent that a miner will have a poor lode, but find sufficient tin-stuff in the Caples thereof to remunerate him.

KECKLE-MECKLE. The poorest kinds of lead mines.

KIBBLES. Buckets in which the stuff is brought to the surface.

KIEVE. A vat or large iron-bound tub for washing ores.

KITTING. Thieving in combination. A takes a pitch wherein he contracts to give the adventurers (owners) of the mine 6s. 8d. out of every 20s. worth of ore he may be enabled to raise during the term of his take and the limits of his pitch. B has a pitch subject to payment of 15s. out of 20s. A and B agree to "kit:" viz. B puts or allows A to put a part of B's ore to A's heap, consequently B's ore, which is subject to a tribute of 15s. to the adventurers, pays thereby but 6s. 8d. There are other modes of cheating the adventurers by miners mixing their ores, and sometimes by stealing from heaps not their own, and carrying to their own heap. All these thefts are called "kitting."

KNOCKER. "The miners say that the Knocker is some being that inhabits in the concaves and hollows of the Earth, and that it is thus kind to some men of suitable temper, and directs them to the ore by such its knocking" (*Hooson*).

KNOCKING-BUCKER. A tool cut out of a strong flat bar for breaking ore or anything that is mixed with ore or *fausteds*.

LACES, STOOPS, or NICKS. Lines cut with the point of a pick on Slickensides.

LATHS. In driving through very soft ground or clearing levels in which there is a great deal of loose stuff, the miners (having first placed pieces of stout timber called "durns") drive planks of stout timber through the stuff; these planks are called *Laths*.

LAUNDER. A trough of deal boards for conveying water, or slime-water, from one point to another.

LEADS. Small fractures in the rocks, frequently connected with veins.

Leap. A term used in mining to express the apparent movement of the lode; as when the vein is thrown from its perpendicular course, at once, into the side.

Leavings. Leavings rarely applies to copper dressing, but to tin, where the small quantities of that mineral which has mixed with the general refuse *in slime or row* become (agreeably to the established contract custom between the tributers and the owners of the stamps) the property of the latter as part payment for the use of the said stamps.

Leppey. Work which is easy, "soft, kind, and winable, without any hardship, as boring, cutting, blasting," &c.

Levels. Horizontal galleries in a mine.

Lifter. The stem of iron attached to the stamp-head.

Limp. A tool for separating ore.

Load of Ore. In the customary Liberties of Derbyshire ore is never weighed. Nine dishes—which hold exactly eight quarts of water—make a load.

Loch Holes. Cavities, vughs.

Lodes. All metalliferous veins.

Lode Slovan. When miners bring up a drain on the course of a lode, particularly in a low marshy place, they say, "We are bringing up a lode slovan 'pon the lode." This is done for the two-fold reason of developing the appearances in the lode shallow, as well as to form a drain for the lode when it has been thus traced into higher ground.

Loobs. Tin slime or sludge of the after-leavings.

Lord's-Mear. The portion which belongs to the lord.

Loughs. Derbyshire levels.

Mallet. A hammer used for driving the borer into the rock.

Matrix. Mineral associated with ore.

Mear of Ground. The length of 29 yards, in Derbyshire, kept by placing a small "stoice" or "stows" at the end of it.

Mear Stake. A large stake driven in the ground at the mear's end.

Middles. Partly concentrated ore, and gangue, forming the middle portion deposited on a buddle or table.

Mineral. "The term may, in the most enlarged sense, be described as comprising every component part of the solid body of the Earth, both external and internal, which is destitute of, and incapable of supporting, animal or vegetable life. In this view it will embrace as well the loftiest pinnacle of the rocky mountain as the most hidden matter beneath the surface of the globe, the hardest and the softest of fossil substances, from the diamond to the sand beneath our feet, the heaviest metal and the lightest tufa." ("The Law of Mines and Minerals," by Wm. Bainbridge.)

Mineral Time. Eight hours' space in Derbyshire and in some other districts.

Mock Ore. A false kind of mineral, sometimes applied to zinc ore (*black-jack*).

Nipper. A tool used by the lander for seizing the kibble, and upsetting it into the wheel-barrow.

Nittings. The ore that remains in the sieve in washing of Smitham which is rounder than the Smitham.

Old Man. "The gear that has been stirred, or cut, before by somebody, which can never happen but in old works, or in old ventures" (*Hooson*).

Packing. A final dressing of tin or copper ore in a kieve or vat with water, after stirring the water and striking the sides of the kieve.

Parcel. A parcel of ore is a pile or heap of copper or lead ore dressed for sale.

Pass. An irregular excavation (generally bored by tributers) from level to level, and then used as a means of communication and ventilation, but chiefly for throwing ores or refuse through.

" The bottom of the hopper placed behind the stamps coffer.

Pee. Two veins crossing each other obliquely.

Pile of Ore. A heap of ore, a parcel of ore, and sometimes a dole of ore.

Pith. The soft part of the lode. In some districts (or rather say in some lodes) the pith consists of steatite—in others soft calcareous spar—in others flukan, and in others a limey uncrystalline substance of a great variety of appearances. The *peath* is a great advantage to the miner in hulking the lode.

Plate. Black Shale, a slaty rock.

Post. Limestone strata divided horizontally with very thin beds of shale.

Powdered Ore. When a vein is spotted with ore or stones of ore, or when ore is disseminated with vein-stuff, it is designated "powdered or dredged ore."

Prian. White lithomarge.

Prill. A rich part of a stone of ore—also

the result of an assayer's trial of a sample. A miner who attempts to cheat the assay master is said to have "prill'd the sample" by unfairly slipping in a bit of superior ore with the sample to be tried.

PRILL ORE. Solid ore. Pieces and large grains of solid dressed ore.

PUPPET-HEAD. The elevated bearers of the truckles, *alias* sheaves, over which the rope or chain passes into the shaft.

QUARRY. "A quarry is an open excavation where the works are visible at the surface." ("The Law of Mines and Minerals," by Wm. Bainbridge.)

QUEERY. When the lode or rock on which the miner is driving partakes of the character of quarry stone, viz. in detached lumps by natural divisions, it is called *queery ground*, and is frequently worked with crowbars and such-like levers instead of being blasted or gadded. A "queer of ground" means a detached rock.

RACHILL. Small loose stones that are usually found on the top of the rock, forming as the depth increased into the nature of beds.

RAFF WHEEL. A wheel with buckets inside of its periphery.

RAGGINGS. Small pieces of ore attached to veinstone.

RECK or RACK. A wooden table (placed a little on the slant) over which slime tin is washed by women.

RIBB. Lines of ore in the veins.

RIDDLE. A large iron sieve for sifting ore —a coarse sieve.

RIDER. A stone running in a vein by which the body of it is divided.

RIFFLE. A ledge placed across a buddle or table, sometimes a bar made across a table.

RISE. This is the same meaning as *Stope*, or excavation in the back of a level. Frequently when a miner who has just left his work is asked where he has been, his reply is, "I *belong* (viz. I work) up in the *rise*." All excavations upwards.

ROUGHS or ROWS. Tinstone enriched to afford 65 to 70 per cent. of oxide of tin is termed "crop." Poorer and larger grain-stuff containing a variable percentage of tin is called Roughs or Rows.

RUTE. A small thread of ore, same as "Scrin."

SAMPLE. Taking certain portions of tin, copper, lead, blende, or other ores for assay purposes.

SARCENS. Strangers. See Attal-Sarsen.

SARVEE. "The country people did make them pay *sarvee* for every particular thing."

SCALL. Loose ground; *foliated* ground is frequently called *scally* ground by miners.

SCOVANS. Small veins, so called in St. Just.

SCOVANY LODE. A lode in which there is no gozzan, flukan, pith, or other advantage for working, is called a "scovany lode." Frequently, although small particles of gozzan are found in lodes, they are called by the miners "scovany," but in nineteen cases out of twenty these have been composed of peach, mundic, hard caple, and killas.

SCRIN. The least or smallest kind of vein.

SCROWL. In many of our (Cornish) mining districts a thin (sometimes calcareous and sometimes silicious) substance struck against the wall of the lode, the miner calls the "scrowl" of the lode;—if of good appearance it is considered by him a favourable omen.

SEVERALL. A name formerly given to enclosed lands. "In *Severall* no man can search for Tynne, without leave first obtained from the Lorde of the soile; who when any mine is found, may work it wholly himself, or associate partners, or set it out at a farme certain, or leave it unwrought at his pleasure." (Carew's "Survey of Cornwall," ed. 1769.)

SHAKES. Caverns in lead mines.

SHAMMELS. Plots or stages fixed in an open working.

SHOAD (from *Shutter*). To pour forth.

SHODES (from *Shutten*, to put forth). Scattered stones found in streams.

SHOOTING NEEDLE. A copper bar with iron head for driving through the tamping and charge to admit the rush, quill, or fuse, previously to blasting a hole.

SIEVE MESH. The length of the side of a hole in a sieve.

SIEVE RAGGINGS. Pieces of ore deposited at the bottom of a sieve.

SILL. A piece of wood placed across a drift, probably derived from the Saxon *syl*, a threshold.

SINK. An excavation under a level, viz. adit or other level.

SKIMPINGS. Worthless sand obtained from the jigger or tozing kieve. The refuse taken from the top of the sieve in jigging.

SLIDE. A fixed incline composed of bars of iron set at given distances apart.

SLIME ORE. Finely pulverised mineral mixed with water in the state of slime or mud.

SLIP JOINT. A dislocation in a slanting direction.

SLOVAN. The *cropping out* or *back* of the lode. This generally applies to the appearance of a lode in a marshy place. N.B.—*Cropping out* is a Welsh, also East and North of England, term—but is never used in Cornwall.

SLUG. A loop formed at the end of a rope through which a miner passes his leg previously to descending an old shaft or working. The other end of the rope, also a signal rope, being left in the hands of the miners at the surface, who lower their comrade and attend to the signals he may communicate during his reconnoitre. A slug is also in common use in a mine by miners in lowering their comrades into old workings, &c.

SMALL ORE. Copper, lead and blende ore dressed to a small size.

SMALL TIN. Tin dressed from slimes.

SMALLS. Gangue and ore of a small size.

SMITHAM. The smallest of the ore that goes through the wire bottom of the sieve.

SNOFF or SNUFF. A bit of paper about 3½ inches long, prepared with grease and gunpowder and placed across the rush when fuse was not used; viz. one kind being fastened to the rock with a bit of clay, and the other end having passed about 2½ inches over the rush; this end was then ignited, and the miner ran to a place of safety to wait the effect of the "snoff" communicating to the charged rush and thence to the charge.

SOLLAR. A chamber (also resting-place) generally about 10 fathoms apart in the footway shaft.

SPALL. To spall, or to break, large stones to about the size of road metal.

STALCH. A mass of ore left uncut when other work has been done around it.

STALL. Platform on which ores or deads are deposited; sometimes a reserve place for deads, thereby saving the expense of drawing it to surface; this would only occur in old mines where stalls are frequently placed in old excavations.

STENT. An abbreviation of extent, and means the limits on which the pitch or bargain is taken—Rubble, waste.

STEWARD. The person set by the masters of the mine in Derbyshire to oversee the work and the men employed therein; who cut, sink, and drive, as he directs.

STICKING SCRINS. Small veins that do not afford shoulder room.

STOOP (Derbyshire). Forefield of a mine.

STOPE. That part of a vein which is always cut "toploose."

STOPING. Stoping the *bottom* of a level applies to sinkings already explained, and stoping the *back* of a level signifies "rising," which see.

STOWSE (Derbyshire). Drawing apparatus.

STRAKE, or TYE. A kind of narrow buddle used with a quick current of water, for washing the roughest part of stamped tin (called "row"). Also used for dressing crushed lead stuff.

STRECK. Signal word for the whim or tackle to be retrograded.

STUFF. Ore associated with gangue.

SUMPS. Places sunk and drawn under ground below the shaft foot.

SUN VEIN. South veins, or veins running south, or veins discovered on the south side of a hill. Common in the northern counties.

SWEEPS. Buddle brushes or pieces of cloth for sweeping the smooth surface of buddle work.

TACK NOTE. Lease of tack, for any definite term less than a year, of any dwelling-house or tenement, or part of a dwelling-house or tenement, at a rent not exceeding the rate of £10 per annum. Agreement for or with respect to the letting of lands, or for a sett of a mine, &c., for term not exceeding thirty-five years, liable to lease duty.

TACKLE or TAKLE. A windlass.

TAILS. The lower portion of stuff lodged on a table or buddle.

TAMPING. The gravel, clay, &c., driven down on the gunpowder.

TAPISHED. When damps break in "at unawares," and the miner just escapes with his life, he is said to be "tapished."

TAPPET. A boss or disc of iron fixed around the stem of a stamp-head.

TICK HOLES (Derbyshire). Drusey cavities.

TIGHT. This is different from hard. When a miner is driving an end at the rate of 30s. to 50s. per fathom, he frequently breaks the ground without the assistance of gunpowder, but although the end when taken might be *heady* or

queery, or *fair* or *sparry*, yet from change of strata, or other cause, the end frequently becomes so short and crumbly in its nature, that blasting avails scarcely anything, and the pick and gad are useless; the end is then called *tight*.

TIN STONE. Stone or gangue enclosing minute grains of oxide of tin.

TIN STUFF. Tin ore obtained from a tin lode.

TONGUE. A piece of iron or steel projecting from the stem of a stamp-head.

TRELOOBING. Stirring and working the *loobs* or slimy earth of tin, in a slime pit, that the mud may partly wash off with the water and the ore settle at bottom.

TROMMEL. A cylindrical or drum-shaped sieve.

TURBARY. "A right of *turbary* is confined to such a quantity of land as is sufficient for the house to which the common is appendant." ("Law of Mines and Minerals," by Wm. Bainbridge.)

TURBERY. A turf-field.

TURN-HOUSE. Altering the direction of the workings.

TWITCH. The sides of a vein coming closer together.

TYE. The point where two veins seem to cross each other or where two pipes cross obliquely.

" The same as *strake*, but worked with a smaller stream of water.

TYTH. An ancient custom or duty which miners gave to the priests. "In my time (1747) I have known it taken every twentieth dish" (*Hooson*).

UNDERLIER. A shaft having a steep inclination.

VEINIFEROUS ORE. Ore associated with gangue ore or mineral.

VEIN SKIRTS (Derbyshire). The walls of a lode.

VEIN STUFF. Ore associated with gangue.

VESSRY or BOWSE. A very productive part of the vein. See *Carbona*.

VOLUMETRIC GRAINS. Grains of a definite size or diameter, but of a variable density, which fall through water at different rates of velocity.

VUG. A hollow lode is called a vuggy lode. It is also frequently used by miners for cavern—which they call a "great vug," or vugga. If you ask a St. Agnes miner the meaning of the celebrated cavern called the "Seal Hole," he would say, "Why, 'tes a large vugga washed in by the sea *'pon* the *coose* of a lode."

WARGEARE. A general name in Derbyshire for whatsoever belongs to the mine.

WASTRELL. Waste or common land.

"An action of trover was brought for copper ore raised upon Towan, in the parish of St. Agnes, Cornwall, by the lessees of the Lord of the Manor, who was entitled to the toll of tin in all the lands, both customary and freehold, and also in the *wastrell* or common called Towan Common." ("The Law of Mines and Minerals," by Wm. Bainbridge.)

"In *wastrell* it is lawfull for any man to make triall of his fortune, provided that he acknowledge the Lordes right, by sharing out with him a certain part, which they call toll. . . . . The *wastrell* works are reckoned amongst chattels, and may pass by word or will." (Carew's "Survey of Cornwall," ed. 1769.)

WHIM. A rotary machine worked by horses or by steam for drawing stuff from the mine through the shaft.

WHISKETS. Shallow oval baskets.

WHITE TIN. The metal produced by the smelter.

WHITTS. Partially dressed tin-stuff. Applied especially to dressed tin from the stamps floors ready for the *burning-house*, therefore still retaining the sulphur ores which give the mass a *white* metallic appearance. These are removed by burning.

WHOLES. Such ground as has never been cut.

WINZE. A shaft sunk from level to level for ventilation and for dividing tribute ground.

ZAWN. In St. Just, a cavern.

ZIGHYR. A slow stream of water issuing from a crack.

ZUE, ZUEING, or DEZUING. The same as hulking a lode, viz. removing the soft side for facilitating the breaking down the harder part thereof. If a miner is asked, "How is your lode looking?" he will often reply, "I don't know, for I have been zueing (sometimes they say *dezuing*) the lode ever since I saw you last."

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THE END.

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